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EMISSION OPTIMIZATION
OF
HEAT ENGINE/ELECTRIC VEHICLE

PREPARED FOR

AIR POLLUTION CONTROL OFFICE
ENVIRONMENTAL PROTECTION AGENCY

MINICARS, INC.
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The emission evaluations were made with the vehicle in three design phases. The tests for the three hybrid designs indicated a marked reduction of exhaust emissions with the delayed throttle control and increased electrical power. The heated manifold allowed leaner air/fuel mixtures to be used and resulted in lower exhaust emissions. The best emission reductions were approximately 60% reduction in ~~HC~~ hydrocarbons and carbon monoxide and 25% reduction in nitrogen oxides when comparing the baseline heat engine with hybrid power trains. The comparisons hold for both concentration and total mass-type measurements with the vehicle on the California 7-Mode Driving Cycle.

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SUMMARY

The basic purpose of this study was to determine the relative reduction in exhaust emissions obtainable from a heat engine/electric hybrid vehicle when compared to the same vehicle powered by a heat engine alone. Emission measurements were made of the hybrid vehicle in its original design state as well as emission measurements of a modified and improved hybrid design.

The emission evaluations were made with the vehicle in three design phases. The major design changes are listed as follows:

Phase I Vehicle in original hybrid design - Hybrid B

- Single venturi carburetor and manifold with heated intake air.
- 24-volt electrical system with on/off controls operated by intake manifold vacuum signal.

Phase II Electrical power increased and a delay throttle control installed - Hybrid C

- Single venturi carburetor with heated intake air and delayed throttle control.
- 24-48 volt electrical system with improved electrical control.

Phase III Vehicle engine manifold revised to burn leaner air/fuel mixtures - Hybrid C-1

- Single venturi carburetor with heated intake air plus heated manifold legs for better mixing of fuel and air.

The tests for the above hybrid designs indicated a marked reduction of exhaust emissions with the delayed throttle control and increased electrical power. The heated manifold allowed leaner air/fuel mixtures to be used and resulted in lower exhaust emissions. The best emission reductions were approximately 60 percent reduction in hydrocarbons and carbon monoxide and 25 percent reduction in nitrogen oxides when comparing the baseline heat engine with hybrid power trains. The comparisons hold for both concentration and total mass-type measurements with the vehicle on the California 7-Mode Driving Cycle.

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I. INTRODUCTION

A prototype, heat engine/electric hybrid vehicle was built during August and September 1969, powered by a nominal 20 hp DC electric motor and an internal combustion engine (ICE) of approximately 40 hp rating. The vehicle, initially designed as an ICE power train, has a safety frame and plastic protective bumpers and was to be used for an experimental urban mass transit system. This initial work was sponsored by the Department of Transportation, Contract PA-MTD-8/H-830. Late in the contract effort a parallel hybrid ICE-electric power train was installed for demonstration purposes. The power train design and development was severely limited due to short installation time and therefore was considered a zero-order hybrid drive train.[1*] The prototype vehicle is shown in Figure 1. While far from a production prototype, the vehicle does allow some answers concerning ride, handling, suspension, safety and power train performance. Preliminary exhaust emission tests showed some reduction in unburned hydrocarbons (HC) and carbon monoxide (CO).

Since a hybrid vehicle was readily available, it became desirable to obtain further exhaust emission information with a minimum of power train modifications. A contract was initiated in June 1970 for further emission tests of the prototype heat engine/electric power vehicle with some improvements being made to the power train and its controls. The evaluation of this power train was divided into three phases. Phase I of the contract was to determine the exhaust emissions of the hybrid power train in its original state of design as baseline tests. Phase II included changing the power train to add more electrical power and to improve the electrical and ICE controls for improved vehicle operation and reduced exhaust emissions. Phase III involved changing the air/fuel (A/F) ratio of the intake air,

[*] Numbers refer to references listed in Appendix.

retarding the ignition timing of the ICE and other engine modifications to reduce exhaust emissions.

II. HYBRID POWER TRAIN

A. Mechanical System

Prototype hybrid power train uses a Corvair, 6- opposed cylinders, 164 cubic inch displacement, aluminum engine for the ICE. The vehicle power train components are shown in Figure 2. The physical components and some of the vehicle specifications are listed as follows:

Car weight	3,200 pounds
Car wheelbase	60 inches
Car frontal area	25 square feet
ICE (Corvair)	6 cylinder opposed 164 in.^{3} piston displacement Air-cooled 8/1 compression ratio
Motor/Generator	Lear Siegler G22-3 24 VDC and 48 VDC Batteries (8 or 12)
Drive Train	Automatic transmission 2.0/1 stall ratio at 1,400 rpm 1.82/1 low and reverse gear 3.57 axle gear ratio 6.90 x 13 tires

The ICE used on this first prototype car was altered to run clockwise rotation instead of the original counter-clockwise rotation used on the Corvair car. No power and fuel consumption tests were run on the engine prior to installment in the vehicle. It was installed directly in the car and the car power was measured on a Clayton EC-200 chassis dynamometer for evaluation. The power output measurement of the ICE via the transmission, final drive and tires becomes difficult to determine with this type of test arrangement. Power at the wheels were determined for both ICE only and hybrid ICE/electric power train operation on the chassis dynamometer. The maximum power output measured at the wheels for ICE only, Hybrid B and Hybrid C power trains are shown in Figure 3. The power train configurations are detailed in Appendix C. ICE only describes the power train using only the ICE power; Hybrid B is the ICE/electric power in original condition, 24 volts and bang-bang electric controls; and Hybrid C is the power train with increased electrical power and improved controls. These power runs are at constant speeds with ICE at full throttle and the electric power at maximum steady state power condition.

In general, to approximate the additional power from the sources, 0.12 times the velocity in mph can be added to the values shown in Figure 3 for transmission, final drive and tire losses. This will give approximately the following power outputs at the ICE and electric motor:

VELOCITY mph	ICE hp	ICE + HYBRID C hp
30	25	41
40	32	48
50	41	54
60	47	57

B. Carburetion

The 6-cylinder, air-cooled, opposed cylinder engine employed in the hybrid power train was operated with a single-venturi carburetor. Besides the choke operation of the carburetor, there are four fuel circuits that are important. These are the low speed fuel system (idle jet), the main fuel system (main jet), the maximum power fuel system (power jet) and the enrichment system (accelerator pump). The low speed system is dominant at idle and low car speed and load conditions. The main jet is dominant at medium and high vehicle speeds. The power jet is dominant at full throttle. When there is a sudden vehicle acceleration, these systems do not provide the required rich air/fuel ratio to prevent the car from "stumbling" so an enrichment pump system is needed. The sudden throttle opening during vehicle acceleration leans out the air/fuel mixture supplied to the intake manifold. To correct the lean mixture, the accelerator pump supplies additional fuel. In fact, the mixture is made richer than normal to provide smooth engine and thereby resulting smooth vehicle acceleration without "stumble".

Normally the Corvair engine used in hybrid vehicle operates in the 11 to 13 to 1 air/fuel ratio range. However, in the latest Corvair engines with exhaust emission equipment such as an air injection reactor (AIR), the normal operation has been leaned to approximately 14 to 1 air/fuel ratio. The engine used in Prototype B hybrid was a lean engine in the 14 to 1 range and in order to evaluate the effects of hybrid operation exclusively, the AIR equipment was removed. The air/fuel ratio was determined by the amount or carbon dioxide and carbon monoxide in the exhaust.[2]

C. ICE Intake Manifold Design

The intake manifold of the ICE was especially designed for this series of emission testing. Since A/F was to be varied in the Phase III tests, a single venturi carburetor was selected with a single carburetor manifold. This intake manifold replaced the dual carburetor assembly on the original Corvair engine. The vehicle became more reliable and required less tuning to keep operating with the single carburetor assembly.

Figure 4 shows the manifold and carburetor used on the engine. The particular manifold shown is the configuration used on Hybrid C-1. The exhaust gas heating pipes and the variable jet on the carburetor are readily apparent in the photograph. Schematic diagrams of the manifold and carburetor are shown in Figure 5. The upper schematic of the figure shows the manifold in the original design used for Phase I and II tests. The lower manifold design was used for Phase III tests. The main difference is in the size of the intake manifold legs, which are 1-3/4" in diameter for the original design and 1" in diameter for the later design. The diameter of the legs were decreased to induce more turbulence in the intake fuel/air mixture in the Phase III tests to allow better mixing of lean fuel/air charge. Also, more heating was applied to the incoming mixture to enhance mixing.

The approximate temperatures of the exhaust gas heated manifold were increased to 190°F whereas in the original manifold the temperature was 100°F. Both temperatures were measured at the end of the manifold leg and with the incoming air at the carburetor approximately 120°F. The original manifold did not allow air/fuel ratios above 15/1. The exhaust gas heated manifold operated at 18/1 air/fuel ratio.

D. Delayed Throttle Transient

The most important design configuration during this hybrid investigation is the concept of delaying the throttle in the carburetor of the ICE during transient operation. In hybrid vehicles, and especially in a parallel hybrid such as the vehicle being used for these tests, the problem of reducing ICE transient operation becomes important. The main objective of hybrid operation in this study is to keep these engine transients low. With lower transient operation the ICE should have exhaust emission similar to that of a steady state operation ICE. Since the preliminary hybrid design did not remove the transient operation as much as desired, a throttle and electrical control was designed to produce a more steady state ICE operation. The advantages of such a control system are as follows:

1. In steady state operation on level, uphill or downhill, the engine provides all the power plus charging power to the storage batteries independent of steady state driving conditions.
2. As the vehicle power is changed quickly, the engine power changes very slowly, thereby operating nearly as a steady state engine. This keeps the air/fuel mixtures ratio nearly constant which in turn should keep the exhaust emission concentrations more nearly constant. The acceleration power needed to change the driving mode quickly comes from the electric system.
3. The control system should be cheap, reliable and easy to adjust or repair.

A throttle delay mechanism was built and tested. The delay system incorporated a hydraulic cylinder which passed a fluid through an orifice to give a delayed lever action. The hydraulic system is described in the schematic diagram shown in Figure 6. As shown in the schematic, as the foot throttle is depressed, the foot throttle lever moves at the same rate but the carburetor throttle lever is delayed by the piston in the dashpot. The two levers are connected only through springs. The rate in which the carburetor throttle lever moves depends on the opening orifice size in the dashpot. Conversely, as the foot throttle is released the carburetor throttle lever will not return at the same rate. This rate is controlled by the closing orifice in the dashpot.

Figure 7 shows the intake manifold vacuum changes as the engine is driven through the California 7-mode driving cycle during emission tests. The bottom trace in the figure indicates a Phase I test without throttle delay. Notice the sudden changes in intake manifold vacuum which indicates sudden changes in carburetor throttle. The upper trace shows the more gradual changes in vacuum indicating slower throttle response. These gradual changes are apparent when comparing the vertical changes in the vacuum traces. The throttle delay trace vertical lines have more slope. Also note that the engine is being unloaded more in Phase II tests due to more electrical power being available. The decrease in average intake manifold vacuum for Hybrid C (Phase II) engine is due to increased gas temperatures in the manifold. The higher volumetric flow rate is required for Hybrid C to maintain the same mass flow rate as Hybrid B.

The parallel hybrid electric system is designed for simplicity and low operating cost, with the objective of improving the emissions of the ICE. The two systems investigated, designated as Hybrid B and Hybrid C, are basic in nature, their only objective being to verify whether parallel gasoline-electric hybrids are feasible and worthwhile. The major control parameter of Hybrid B was the intake manifold depression which regulated the field current of the DC machine. In this configuration, both manual and three types of automatic controls were evaluated -- on-off system, a step-wise system and a continuous modulation system (see Appendix C).

Based on tests performed on Hybrid B the following factors were singled out as possible sources of problems:

1. In the automatic control mode (all three types) vacuum oscillations caused an erratic operation of the control system.
2. The power ratioing between ICE and electric systems during the cycle was found to be improperly adjusted for best emission characteristics. The electric system of Hybrid B could supply only 10 hp peak, while calculations for 3,000 pound vehicle showed a need for 25 hp.
3. A speed variation of only 1.5:1 could be obtained under load from the electric machine using only shunt field control.
4. The engine experienced sharp changes both in speed and power output, since sufficient power could not be delivered from the electric system.

To overcome the above mentioned problems a new system, Hybrid C, was designed, based on the fact that the ultimate goal of the gasoline engine/electric motor hybrid system in this particular study is to reduce exhaust emissions by preventing sudden throttle valve changes during vehicle acceleration or deceleration. The new system connects the engine throttle to the foot accelerator pedal through a spring with a strong viscuous damper. This allows the throttle to follow the foot pedal with an exponentially decaying response having a time lag of some 2 to 3 seconds (or adjustable as required). The difference in the angle of the throttle and foot pedal would be the main control for the motor/generator field current. When the foot pedal is depressed further than the spring-damper system moves the throttle, the motor is in operation. Once the foot pedal is brought back to some lesser angle, the throttle comes back slowly and the electrical system is generating current to the batteries. When both foot pedal and throttle are at the same angle, the electrical system is also generating. A diagram for this system[3] is shown in Figure 8.

To implement Hybrid C, the following steps were undertaken:

1. The vacuum controller was removed since under optimal operation the vacuum should be constant. In its place a pedal actuated motor/generator control was installed, based on the angle difference between the accelerator pedal and the carburetor butterfly.
2. A new solid state controller (Figures C3, 4, and 5 of Appendix C) was designed and installed, where power ratioing is an adjustable parameter.
3. A parallel series relay for battery switching was installed to provide for voltage switching, and thus increase the power output and the speed regulation of the electric machine.

4. A dashpot/spring mechanism was installed to introduce a delay to the ICE and a smooth transition from one steady state to another.

5. Additional batteries were added (see Figure C2 of Appendix C).

Appendix C gives a complete wiring diagram of both Hybrid B and Hybrid C, although only Hybrid C is relevant and in operation at the present time.

III. EMISSION TESTING

The exhaust emission tests were conducted at the APCO Federal Laboratories in Los Angeles. The vehicle was installed on the Clayton Chassis Dynamometer and both concentration type and constant volume sampler (CVS) type measuring instrumentation was used to measure exhaust emission of the vehicle. Figure 9 shows the vehicle emission test set-up. Both California 7-mode and DHEW driving cycles were used. Hot and cold 7-mode cycles were evaluated. These emission test procedures are described in a California Air Resources Board 1968[4] report, and in Federal Registers of 1968 and 1970[5,6]. The California 7-mode and the DHEW driving cycles and the concentration and CVS measurements are briefly presented in Appendix D. The DHEW cycle is 1,370 seconds long, which is ten times longer than the California 7-mode cycle which is 137 seconds long. The CVS emission measurements, on both the 7-mode and DHEW driving cycles, give total mass emission throughout the entire cycle. The concentration type measurement breaks down the emissions for each mode measured, and was used only on the 7-mode cycle. Since not all of the 7-mode driving cycle is measured with the concentration type measurement and the calculated exhaust volume flow tend to be lower than the actual measured exhaust volume flow, the CVS emission results tend to be higher. The concentration type measurement, however, gives a better indication of the ICE operating condition since the emissions for accelerations, decelerations, cruises and idle modes are separated. Since most of the interest in this study was directed toward electric-ICE system development, the majority of tests were

7-mode with concentration type measurements. CVS measurements were made of some of the 7-mode cycles as well as one DHEW driving cycle.

A. Power Train Effects

The power train variation effects on exhaust emissions are presented in Figure 10. These variations include the following:

1. ICE power (Phase I):
   - ICE power only
   - Carburetor with choke and accel. pump
   - A/F at 15 to 1
2. Hybrid B (Phase I):
   - ICE and 24V electrical system
   - Carburetor without choke and accel. pump
   - A/F at 15 to 1
3. Hybrid C (Phase II):
   - ICE and 48V electrical
   - Carburetor without choke and accel. pump
   - Delayed throttle response
   - Heated intake air
4. Hybrid C-1 (Phase III):
   - ICE and 48V electrical system
   - Carburetor without choke and accel. pump
   - A/F at 16.5 to 1
   - Delayed throttle response
   - Heated intake air
   - Heated manifold jacket

The emission data shows a marked decrease in HC, CO and NO when the ICE and Hybrid C-1 power trains are compared in Figure 10 and also indicated in Table I. The complete emission data for each mode of the 7-mode California driving cycle are presented in Table I.

TABLE I EXHAUST EMISSIONS

MODE	HC ppm	CO %	NO ppm	A/F RATIO	CALIFORNIA 7-MODE CYCLE	
		ICE				
1	285	2.35	101	14.5		
2	312	4.43	495	13.0		
3	148	2.45	768	15.0	AVERAGE	296 ppm HC
4	914	8.73	110	11.5	FOR	3.14% CO
5	166	.21	446	15.0	CYCLE	1183 ppm NO
6	173	1.33	2062	15.0		
7	2438	6.17	102	12.0		
		HYBRID C-1				
1	143	1.22	182	15.0		
2	128	.53	462	16.5		
3	66	.23	906	16.5	AVERAGE	122 ppm HC
4	211	5.11	276	14.0	FOR	1.2% CO
5	97	.26	752	16.5	CYCLE	917 ppm NO
6	94	1.28	1083	14.5		
7	107	.73	1162	15.0		

Concentration type comparison is shown above and does not reflect the total mass emissions.

The Hybrid C-1 engine runs with a leaner A/F ratio than the all ICE power train. The ratios range from 2 to 3 A/F numbers leaner for the Hybrid C-1. Operations of engines with leaner than 17/1 A/F ratios gave erratic engine operation with backfiring through the intake manifold and misfiring in the cylinder. The air/fuel measured at 30 mph cruise (Mode 3) is used as a representative ratio for the entire cycle. Since most of the driving modes are transients and the engine has a greater amount of cyclic variations during transients, it is desirable to measure A/F ratio during steady state cruise condition. The power output at 30 mph is a good average for the 7-mode driving cycle. This hybrid run, shown in Table I, of 16.5 to 1 A/F ratio provided smooth, suitable operation; but similar A/F settings for the other runs gave unstable operation. Most runs were made at 16 to 1 or lower A/F ratios to provide acceptable engine operation for Hybrid mode while ICE-only required 15 to 1 A/F ratio.

B. Vehicle Weight Effects

Figure 11 shows a summary of measured data versus vehicle weight. The data shown include HC, CO, NO, fuel used per cycle, and A/F ratio at steady state 30 mph operation. The various power trains used are shown in the Figure. The hot California 7-mode cycle was used for these tests. Vehicle weight was simulated by using 2,000 lb., 3,000 lb., and 4,000 lb. flywheel weights of the Clayton Chassis Dynamometer.

In ICE-only operation, the vehicle weight effects on emissions resulted in slight increases of HC and CO and a decrease of NO with increase of vehicle weight. NO decrease is probably because of the righer A/F ratio supplied to the engine as weight was increased.

Hybrid B operation showed about the same results except for NO which remained relatively constant with increased vehicle weight. The A/F ratio remained constant for all these runs.

Hybrid C operations indicated a more erratic behavior. HC remained constant, while CO increased and then decreased with vehicle weight increases. NO increased markedly with increased vehicle weights. Also, A/F ratio decreased and then increased with increased vehicle weight. The barburetor jets were constant so the change was due to fuel circuit change.

C. Cruises

Steady state cruise tests were run with the vehicle using ICE and hybrid power. Table II shows the comparison of the measured data for the vehicle in Phase I, Phase II, and Phase III conditions. In general, the data indicate the following:

TABLE II

(15-30-50 MPH CRUISES CONCENTRATION OF EXHAUST EMISSIONS)

	VELOCITY mph	ICE POWER hp/whls	FUEL mpg	ENGINE rpm	MANIFOLD "Hg VAC"	A/F Ratio	HC ppm	CO %	NO ppm
PHASE I TESTS									
ICE	15	1	13.7	1550	11	15/1	101	.9	458
	30	3	17.8	1625	7	15/1	73	1.0	972
	50	8	16.0	2650	9.5	15/1	112	1.0	3383
HYBRID B	15	1*	9.6	1525	9	15/1	54	.4	766
	30	6.6	13.4	1650	6.5	15/1	91	1.8	1051
	50	14	9.1	2650	3.5	12.5/1	177	7.5	445
PHASE II TESTS									
ICE	15	1	16.5	1500	12	15/1	167	1.0	534
	30	3	21.6	1650	7.5	15/1	110	2.0	1117
	50	8	17.1	2700	9	15/1	132	1.8	3143
HYBRID C	15	0*	8.6	1500	12	15/1	133	.2	376
	30	6.6	11.2	1600	3	12.5/1	240	7.7	310
	50	14	9.8	2650	2.5	12.5/1	216	7.8	462
PHASE III TESTS									
ICE	15	1	14.5	1530	13.5	15.5/1	188	1.5	468
	30	4	10.3	2900	13.5	12/1	297	9.2	336
	50	16	12.6	2640	8	12.5/1	230	8.6	427
HYBRID C-1	15		11.8	1570	7.5	16/1	145	.2	127
	30		8.8	2960	7.5	15.5/1	177	.2	1056
	50		12.4	2650	6	15/1	512	3.5	1492

* Generator not charging, but in motoring mode, therefore requiring very little power from ICE.

1. Fuel consumption rate is higher for the hybrid in cruise conditions because of additional power being stored by charging batteries in hybrid mode.
2. Manifold vacuum shows the engine is providing more power for hybrid mode.
3. When the engine is near its maximum output during the higher velocity runs, the A/F mixture supplied to the engine is richer which results in higher HC and CO emissions and lower NO emissions.

D. CVS Emission Data Comparison

Table III lists most of the constant volume sampler (CVS) emission data measured from the vehicle employing ICE-only and hybrid power trains. The CVS equipment is described in Federal Register[5] of 10 November 1970. Basically, the CVS equipment dilutes the vehicle's exhaust with air and stores this sample in a bag which is then analyzed by gas analyzers to give a concentration of HC, CO, and NO. The exhaust dilution takes place in a chamber that has known air flow. With a known flow and gas concentration, the mass of each gas may be determined. This measuring apparatus gives the total mass flow for the entire driving cycle. Hot and cold cycles may be separated by catching separate gas samples during the respective cycles. The 7- mode cycle and the DHEW cycle are described in Appendix D.

TABLE III CVS EMISSION DATA (gm/mi)

7- MODE DRIV.CYCLE	BASELINE ICE	HYBRID B	HYBRID C	HYBRID C-1
HC	12.15	6.78	7.6	5.26
CO	128.1	65.3	72.8	27.9
NO	2.15	2.08	2.17	1.59
DHEW DRIV.CYCLE				
HC	-	-	-	3.15
CO	-	-	-	29.6
NO	-	-	-	1.0

The emission comparison shown in Table III of the the ICE and hybrid power trains on the 7-mode driving cycle show the reduction due to hybrid operation as shown before by the concentration measurement data. The HC and CO are markedly reduced -- about 50 percent. Also, as shown before with concentration type measurements, NO does not go down with Hybrid B operation. It is interesting to note that the Hybrid C-1 operation shows a further reduction in HC, CO and NO as shown before with concentration type measurement and this reduction holds even with the DHEW driving cycle.

E. Air/Fuel Effects on Exhaust Emissions

The main jet of the carburetor was varied in size to produce various A/F ratios for ICE intake. The A/F supplied to the engine will vary as the vehicle goes through the different modes in the California 7-mode driving cycle. Table I showed variations of A/F as the vehicle is driven through the 7-mode driving cycle.

Using the A/F ratio of Mode 3 as the average A/F ratio, Figure 12 shows the emission variation of the ICE when the A/F ratio is changed. The test data shown were for cycles where the ICE ran without too much misfire in the combustion chamber or backfire in the intake manifold. Some misfire is evident for the 18/1 ratio which shows a marked increase in HC and some reduction in NO. This increase in HC is to be expected with normal combustion, but not to the great extent as shown; therefore, there must be some misfiring.

F. Effects of Misfiring

On one occasion an ignition wire broke loose during running and caused a misfire in one cylinder of the engine. It is interesting to note the results this has on exhaust emissions. The table below compares a misfiring run with a normal run.

TABLE IV

	NORMAL FIRING	MISFIRING ONE CYLINDER
HC ppm	194	3171
CO %	3.1	2.4
NO ppm	653	951

It is interesting to note the HC and NO increase. HC increase is expected due to one cylinder not firing. NO increase is probably due to the other five cylinders working harder to maintain the vehicle on the driving cycle.

G. Effects of Retarded Ignition Timing

The effects of retarding the ignition timing from the standard ignition timing of the engine are shown in Figure 13. The HC and CO emissions are reduced with retarded timing of 6 degrees, but increase to that of the standard timing when retarded to 14 degrees. The NO, on the other hand, increases at 6 degrees retard and then returns back to its original emission value at 14 degrees retard. The Corvair engine did not operate smoothly in these retard conditions and the emission results are not conclusive.

When an engine operates under retarded ignition timing, the peak combustion temperatures are reduced, thereby reducing the NO emissions. Since the engine used in these tests did not show a reduction in NO, it is evident that the temperatures in the cylinder with retarded spark timing are not reduced. Possibly the air-cooled cylinder engine used in this study does not run with lower combustion temperature with retarded spark timing.

IV POWER SOURCES

In a parallel hybrid system the amount of power delivered or absorbed at any point during the cycle by the ICE and the electric system (power ratioing) is a parameter of major importance, and very difficult to measure since both devices operate through an automatic transmission at varying values of slip and efficiency. The available measuring points, such as electric machine input/output, engine manifold depression and speed and road horsepower and speed (as measured on tye dynamometer) do not give a direct accurate representation of the power output as measured on the road dynamometer, which does not take into account tire losses and slippage, temperature variations as a function of the cycle, etc.

One of the major requirements of the present contract was to measure or estimate the power ratioing in order to provide data to develop a criteria for further optimization of this type of parallel hybrid system.

This section presents the method used to empirically calculate the gross and net power outputs of both the ICE and the electric machine. The battery pack performance, another parameter of major importance, is also evaluated in this section.

A. Power Calculations

The procedure to calculate the gross and net power of each component in the parallel hybrid system is as follows:

1. Measure and record armature current and voltage. Actual motor power output is found by assuming an average electric motor efficiency of 80%. (Per manufacturer specifications.)
2. Using torque converter performance curves and an $\frac{N}{V}$ ratio* of 53 for high gear and 53 x 1.83 for low gear, compute the net (at the road) electrical power. This includes electric power supplied to the road and absorbed via regenerative breaking.
3. Using the calculated net power needed for the 7-mode driving cycle, calculate the net power supplied (absorbed) by the ICE.
4. Perform the inverse of Step 2 to find the gross power supplied by the ICE. This should also include the power needed to drive the generator.

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* N/V = engine rpm/vehicle mph.

Unfortunately, the present parallel hybrid system does not have the optimum components, since available -- off the shelf -- items had to be used due to the short time in which the vehicle was built. Consequently, some parts of the cycle do not match the modus operandi and instead a modus vivendi was accepted. For example, at idle the ICE is supposed to drive the electric machine in the generator mode. But since the idle speed has to be less than a 1,000 rpm, (automatic transmission considerations), and the counter electromotive force is less than battery voltage, even with an overexcited field, the electric machine idles as a motor drawing power from the batteries. If the obvious step of disconnecting the electric machine from the battery pack is taken, a new problem arises, mainly, the ICE stalls when the vehicle is in gear and idling, since the present flywheel is not heavy enough and the idle load is larger than normal.

Although Hybrid B did improve somewhat the emissions characteristics, it was not considered sufficient since the electrical power contribution at each point on the cycle did not exceed 10 percent. Once the baseline characteristics of the vehicle were established the total electric power was defined, based on the criteria that the engine was expected to have a smooth transient from one steady state to another as shown in Figure 14. Thus, the electric power at the wheels was found and calculated at the input using Step 2 above. The new level lead to the decision of adding a voltage switching device for Hybrid C.

The current of the motor/generator was measured, recorded, and is given in Figure F-1, in Appendix F. The armature voltage is also shown in Figure F-1. This graphical data, in conjunction with road horsepower as measured on the dynamometer (Figure 3), with engine manifold depression (Figure 7), engine speed (Figure 15) is used to derive the graphical data for gross powers into the transmission, as shown in Figure 16 and for net power at the wheels as shown in Figure 17. From Figure 17 the information concerning power ratios at any instant of time can be obtained and when the net ICE power output is compared with the desired ICE power output (Figure 14) it is apparent that the actual system does not perform as required for optimal operation.

B. Battery Pack Performance

Tests conducted on Hybrid C also provided information concerning the rates of charge and discharge of the battery packs. Table V shows the specific gravity of batteries operating on a number of 7-mode driving cycles. Figure C-2 in Appendix C is a schematic diagram of the battery pack configuration used in Hybrid C.

TABLE V
BATTERY CHARGE MEASUREMENTS 7-MODE DRIVING CYCLE
Specific Gravity

	7 7-Mode Cycles Cold Start		9 7-Mode Cycles Cold Start	
	Start	End	Start	End
Front batteries	1264	1264	1258	1254
S. front batteries	1284	1264	1260	1254
S. rear batteries	1274	1264	1260	1254
Rear batteries	1282	1262	1250	1240

As can be seen from the table above, the rate of charge and discharge of Hybrid C under the present control configuration was acceptable for the front battery pack. The front battery pack is composed of four heavy duty electric vehicle lead-acid batteries. The two side packs, which were used in order to guarantee that the high electric power needed for the high acceleration would be available from the batteries, were also heavy duty, but of the SLI type lead-acid batteries used in large trucks.

The rear battery pack, which is the original battery pack in the Minicar, consists of four automotive type SLI batteries. These were primarily chosen because their physical dimensions fitted in the available amount of space. Table V shows that standard SLI type batteries were not as good as heavy duty types for hybrid operation. Failure to return to a fully charged state can, in all cases, be attributed to the fact that no charging is available at idle.

In addition to this, the system was also tested with the new proposed DHEW CVS driving cycle (see Appendix D for complete description of cycle). Table VI shows the specific gravity of the battery pack operating on the DHEW cycle.

TABLE VI
BATTERY CHARGE MEASUREMENTS
DHEW DRIVING CYCLE

	Start	End
Front	1274	1278
Side Front	1290	1275
Side Rear	1290	1284
Rear	1300	1290

Comparing Tables V and VI, it can clearly be seen that no significant difference exists in the charge-discharge characteristics of the battery pack between a 7-mode driving cycle and the DHEW driving cycle.

V. CONCLUSIONS

The exhaust emission results of various parameters of the heat engine/electric drive train system were presented in this report. The vehicle parameters studied were power train control, vehicle weight, emission instrumentation, driving cycles, air/fuel ratios, ignition timing, and ICE cylinder misfiring effects. The following is a summary of these test results:

A. The hybrid power train does lower exhaust emissions. When carburetor throttle is delayed during transient accelerations and deceleration, there is a further reduction.

B. Increasing vehicle weight tends to increase exhaust emission concentrations. Not all concentrations were increased,but since the exhaust gas flow increases when vehicle weight is increased, the mass of exhaust emissions per mile is increased.

C. Exhaust emission instrumentation generally shows the CVS measurement higher than the concentration type measurement over the same driving cycle.

D. Comparison of emission data for driving cycles did not show an increase of emissions for the DHEW cycle over the 7-mode cycle.

E. HC and CO emissions decreased, but NO increased when A/F ratio was increased to approximately 16/1. Above this ratio the engine misfired and gave erratic data.

F. Spark timing variations did not show any conclusive results.

G. When the engine misfired during steady state operation (one cylinder not firing at all) there was a ten-fold increase in HC, while CO remained about the same, and NO increased approximately fifty percent (50%).

H. Parallel hybrid power train as used in these tests did not reduce emissions to acceptable levels.

Concerning the performance of the electrical system the following conclusions can be made:

A. Heavy duty lead-acid batteries were found to be acceptable as the energy storage element in the parallel hybrid system for these tests.

B. The shunt DC motor/generator with armature and field control performed satisfactorily in the particular driving cycles tested.

C. The electric machine continuous rated at 9.7 hp was capable of supplying the peak requirements of 27 hp when external cooling was applied.

D. The new solid state controller as described in Appendix C proved to be simple, reliable, inexpensive, and sufficient for the present requirements.

VI. RECOMMENDATIONS

The following recommendations are made as a result of this emission test and control system development work:

A. Since the ICE did not operate at extremely high A/F ratios during hybrid mode, these tests should be repeated using an engine that has been developed on a test stand for this type of operation. (When this development is undertaken, care should be employed in determining the engine conbustion characteristics. Pressure-time instrumentation installed in the combustion chamber can determine the cyclic behavior of combustion. The cyclic scatter of combustion is the most important characteristic in determining smooth engine operation. The larger the combustion variation, the rougher the engine runs. A rough operationg engine causes vehicle surge. Since leaner A/F ratios cause a larger variation of combustion rate, lean engine operation leads to vehicle surging.)

B. The throttle delay and its associated electrical controls should be more fully developed. This concept is a simple and very desirable one for heat engine/electric hybrid control and the preliminary results show substantial exhaust emission reduction. The throttle delay concept should be examined in more detail to determine the amount of emission reduction that can be obtained with various delay times -- both in acceleration as well as deceleration engine transients.

C. A stabilized shunt machine should be tried with an eye to increasing the torque producing capabilities at the low speed range without the need of overexcitation.

D. A more complete evaluation of the proper ratings of the motor/generator is required to find the limits of operation based on more general cycles (such as DHEW) and to reduce size and cost.

E. The hybrid controller should be further developed to provide more and easier adjustments and to be an adaptive controller.

F. It is estimated that the hybrid power train will not, by itself, produce satisfactorily low exhaust emissions. Hybrid power trains may be useful in eliminating peak values of emissions when the vehicle is driven through transient accelerations or decelerations. Exhaust emission devices can then become simpler in design, lower in size, and less likely to experience drastic changes in operating temperatures.

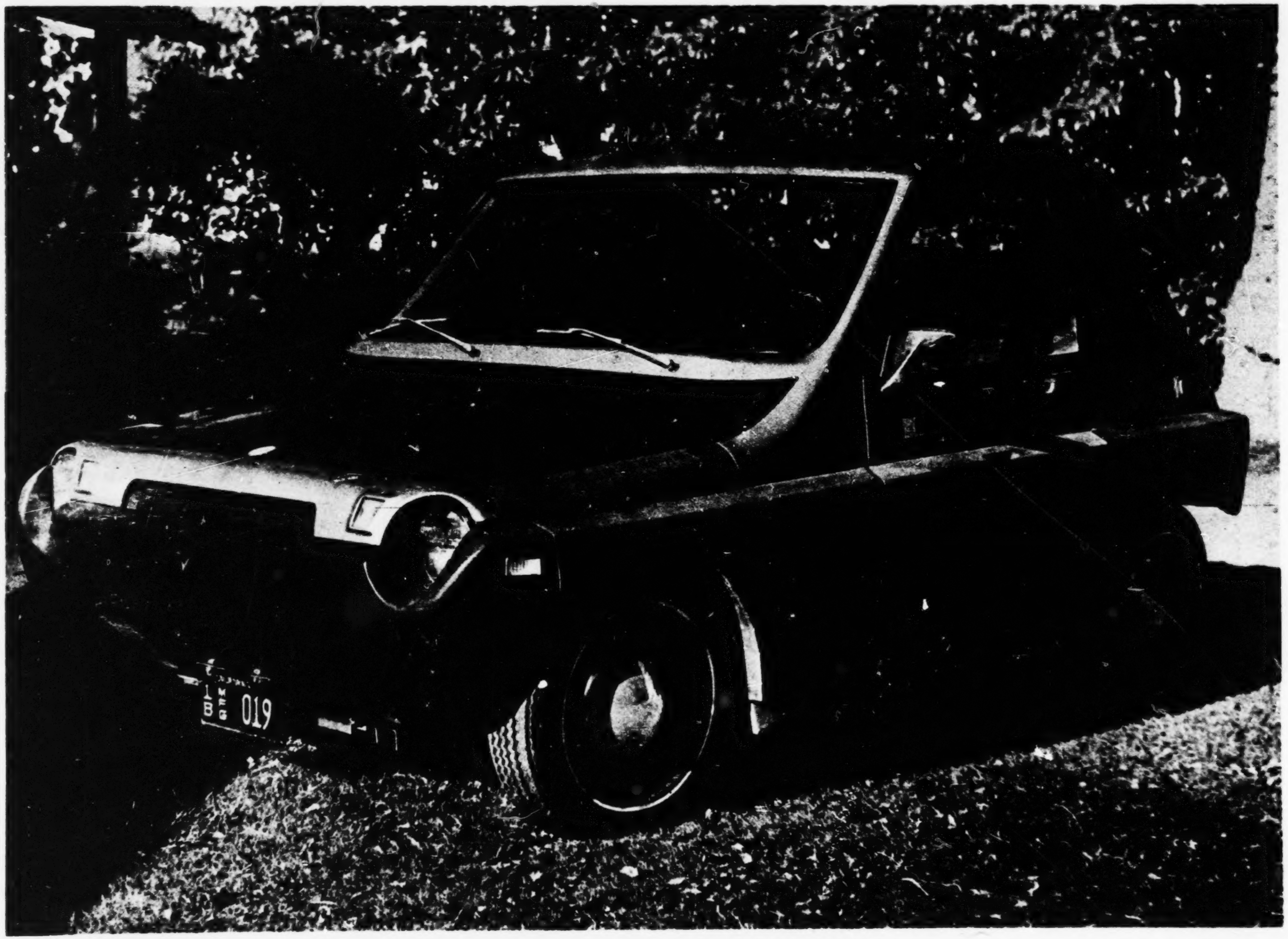


FIGURE 1 - HEAT ENGINE/ELECTRIC HYBRID VEHICLE

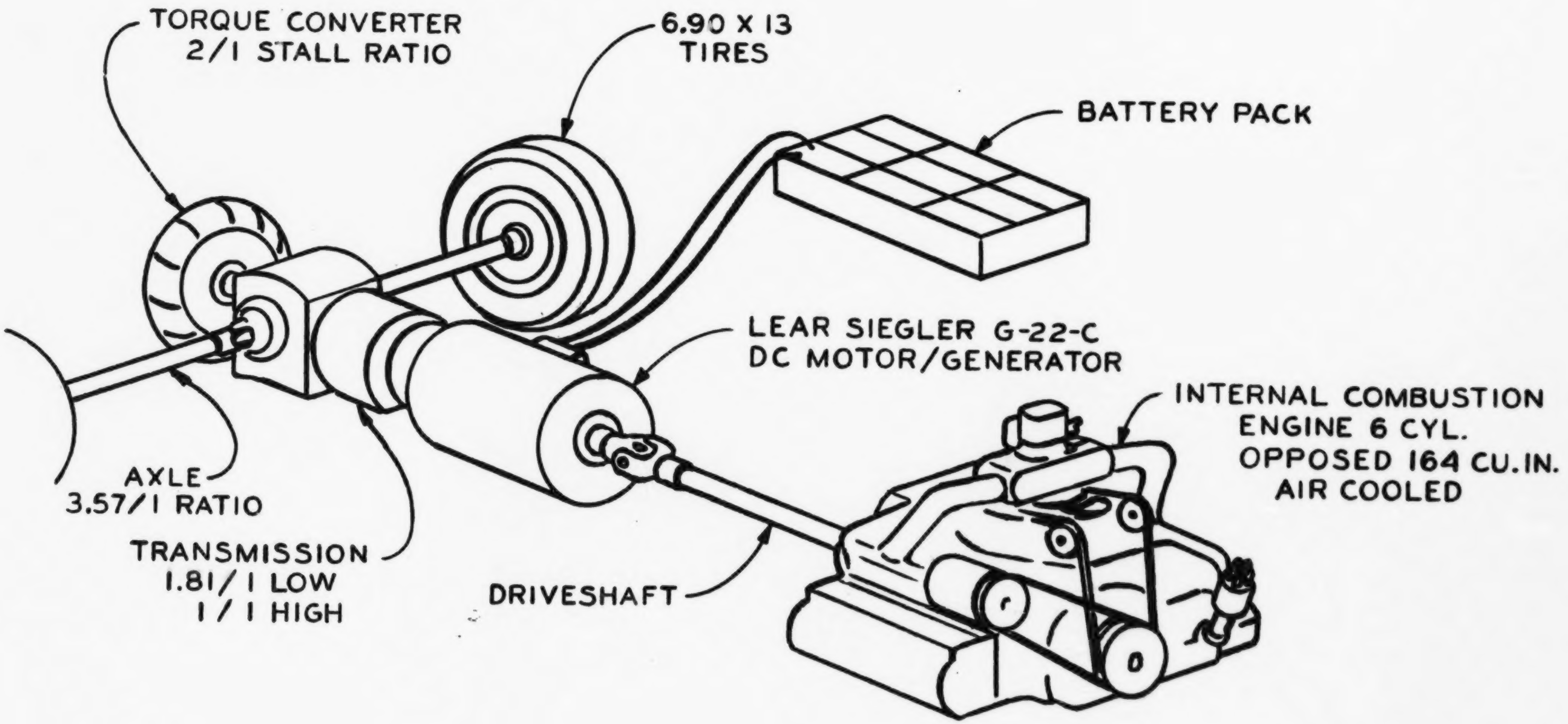
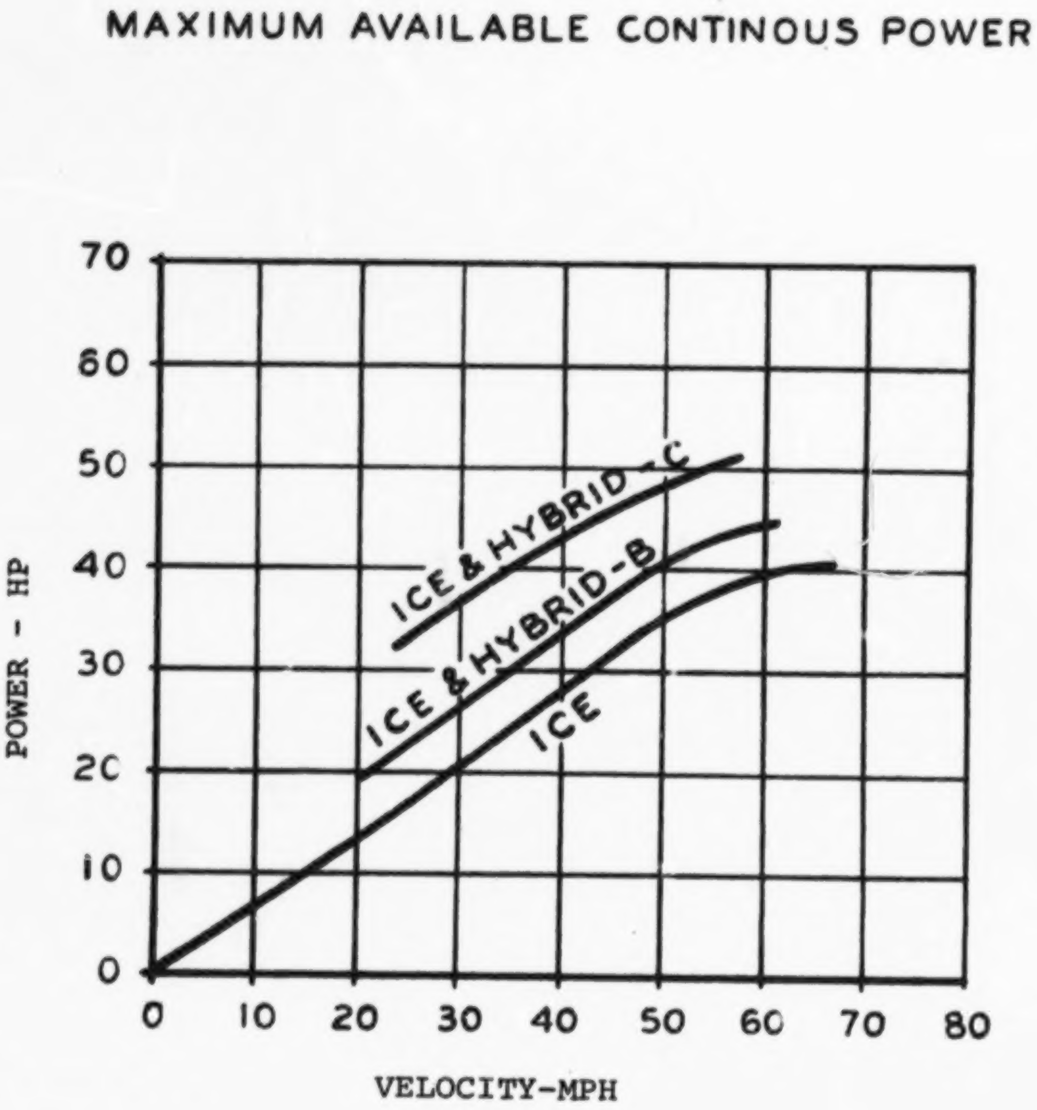


FIGURE 2 HEAT ENGINE/ELECTRIC HYBRID POWER TRAIN



ROAD POWER-CHASSIS DYNAMOMETER

FIGURE 3

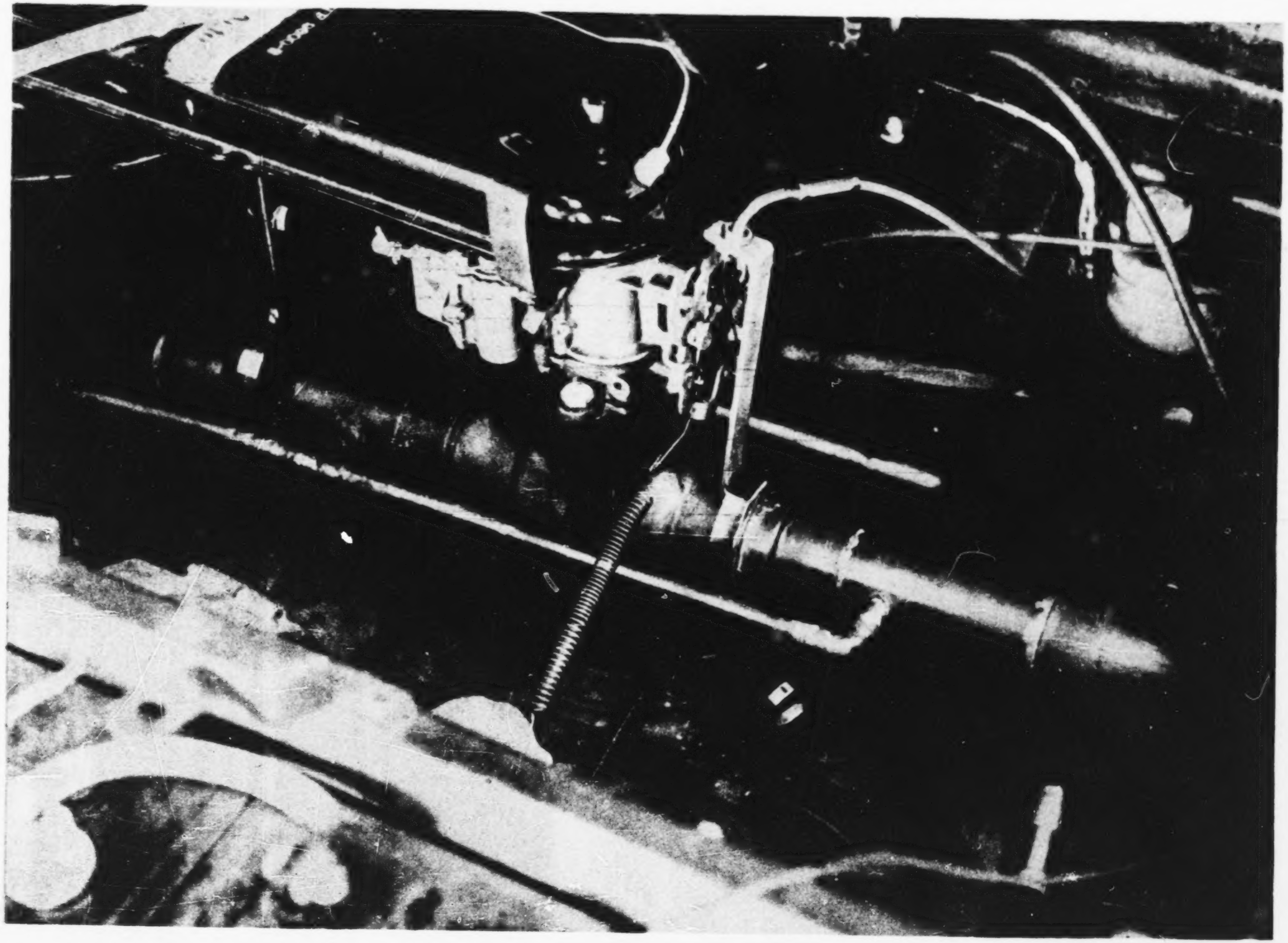
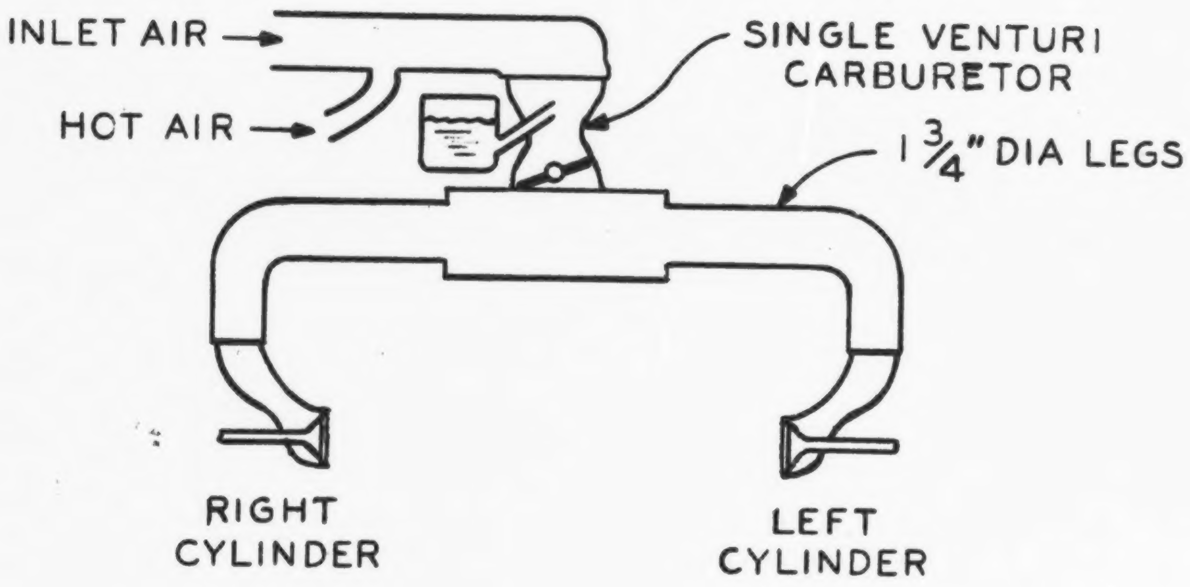


FIGURE 4 SINGLE VENTURI CARBURETOR WITH SINGLE CARBURETOR INTAKE MANIFOLD

HYBRID B & C



HYBRID C-1

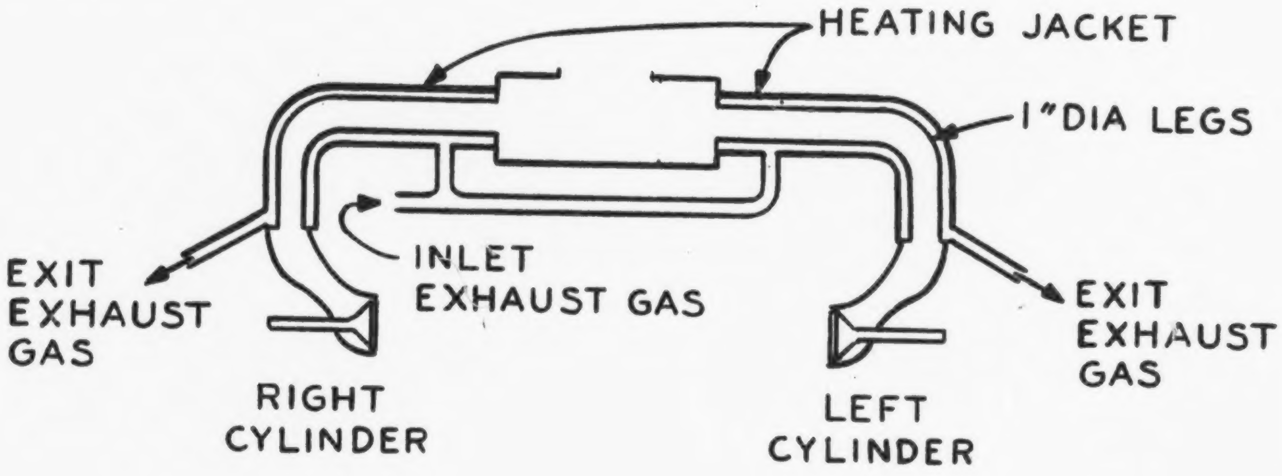


FIGURE 5 SINGLE CARBURETOR MANIFOLDS SHOWING HOT AIR HEATED AND EXHAUST GAS HEATED DESIGNS

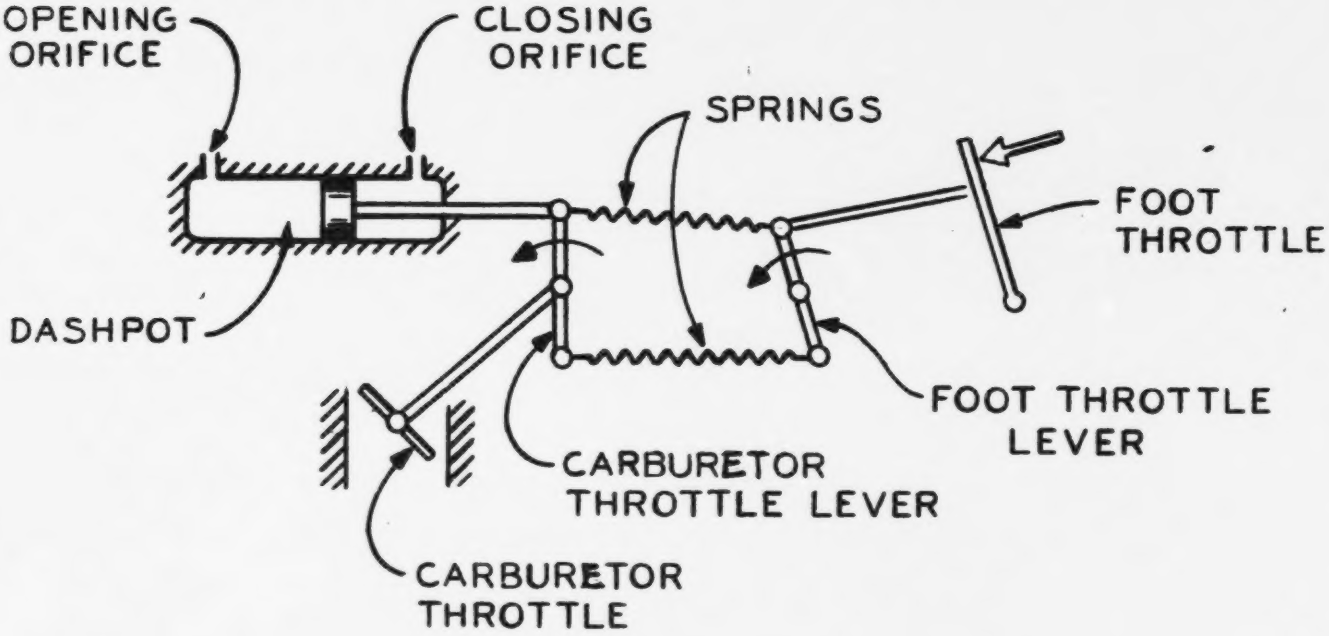


FIGURE 6 MECHANICAL CONTROL SCHEMATIC OF THE DELAYED THROTTLE CONTROL

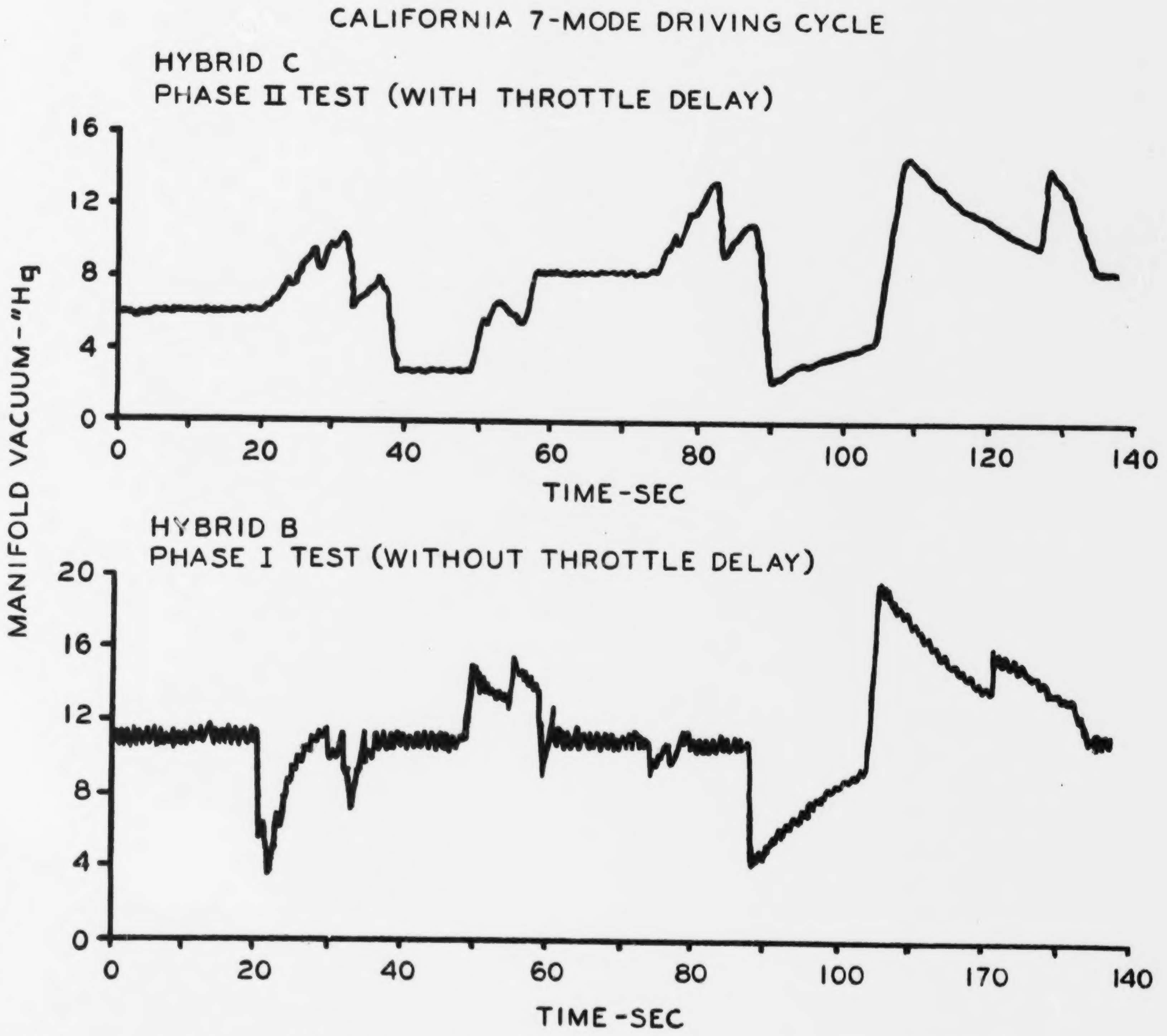
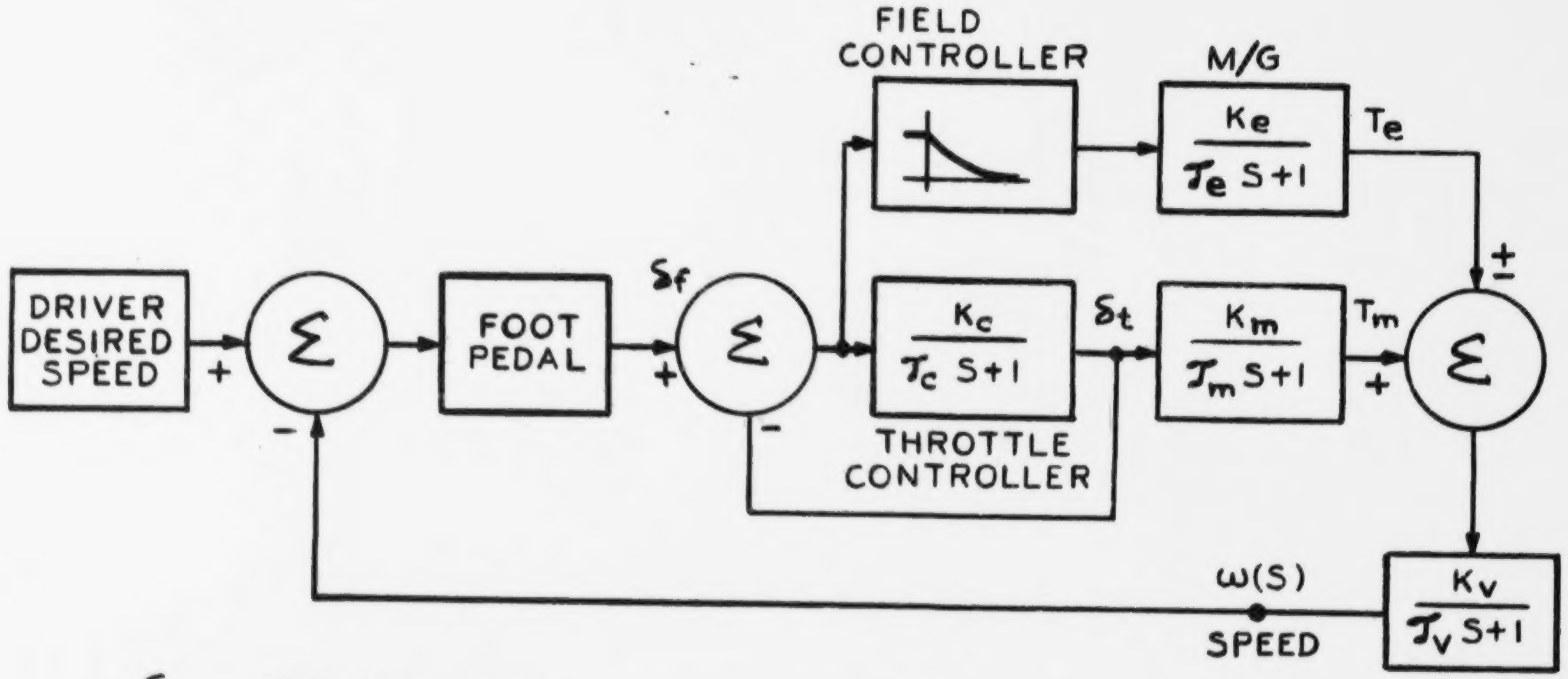


FIGURE 7 - INTAKE MANIFOLD VACUUM WITH AND WITHOUT THROTTLE DELAY.



δ_f - FOOT PEDAL ANGLE

δ_t - THROTTLE ANGLE

T - TORQUE

K - GAIN

S - LAPLACE TRANSFORM

τ - TIME CONSTANT

e - ELECTRICAL

m - MECHANICAL

c - CONTROLLER

v - VEHICLE

FIGURE 8 SCHEMATIC DIAGRAM OF THE THROTTLE DELAY AND ELECTRICAL CONTROL SYSTEMS FOR HYBRID C

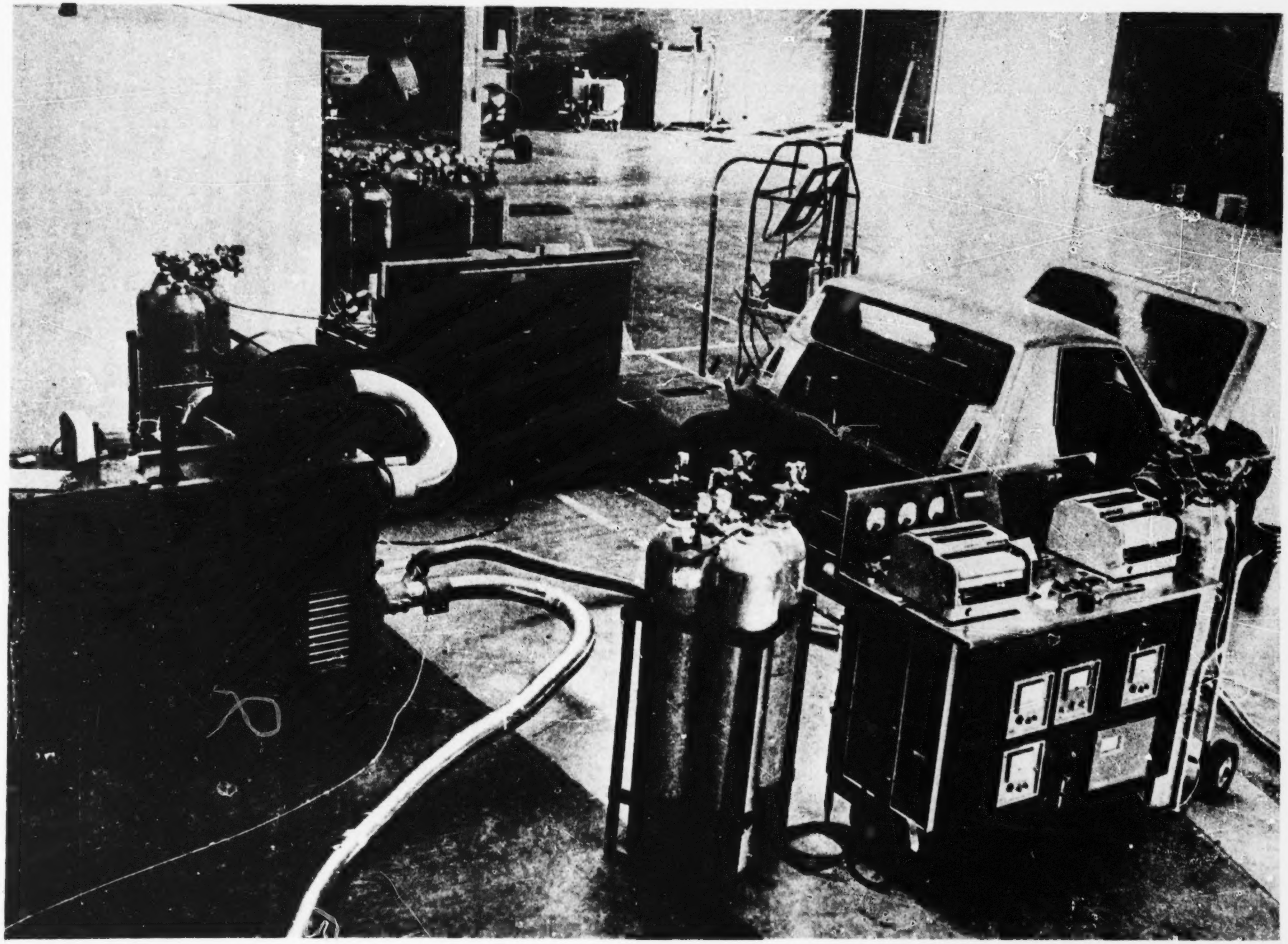


FIGURE 9 EMISSION TEST SET-UP AT APCO LOS ANGELES FEDERAL LABORATORIES

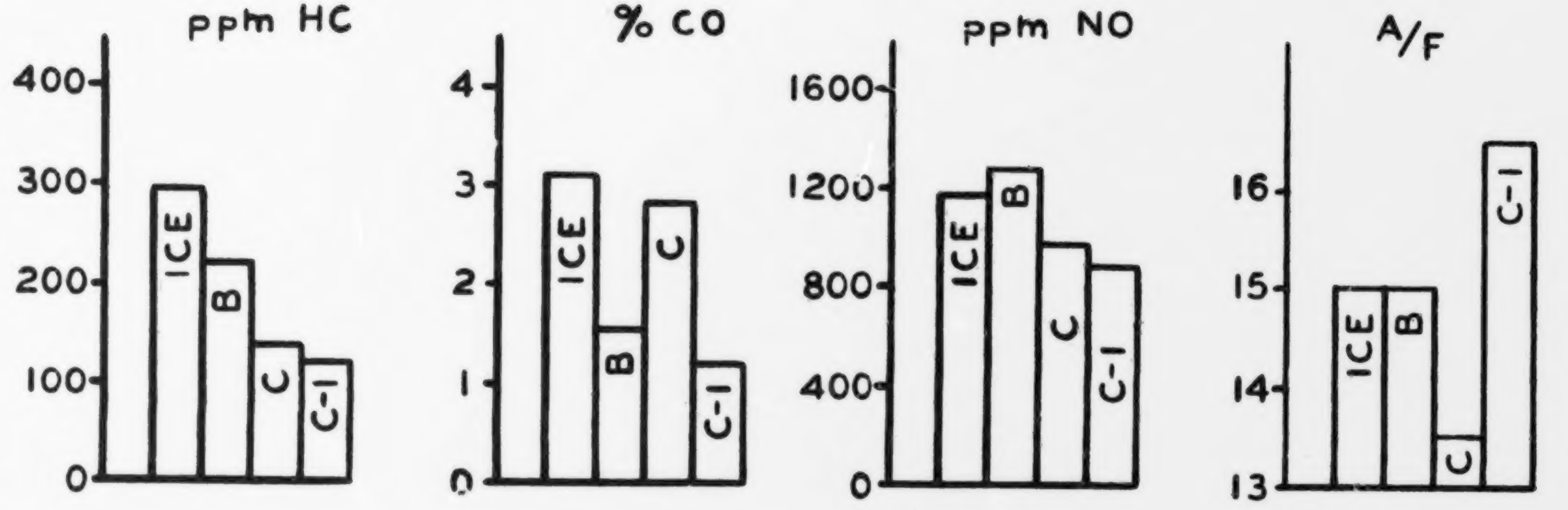


FIGURE 10 EXHAUST EMISSION COMPARISONS OF BASELINE ICE, HYBRID B AND HYBRID C POWER TRAINS. CONCENTRATION MEASUREMENTS ARE PRESENTED WITH VEHICLE DRIVEN ON THE 7-MODE CYCLE.

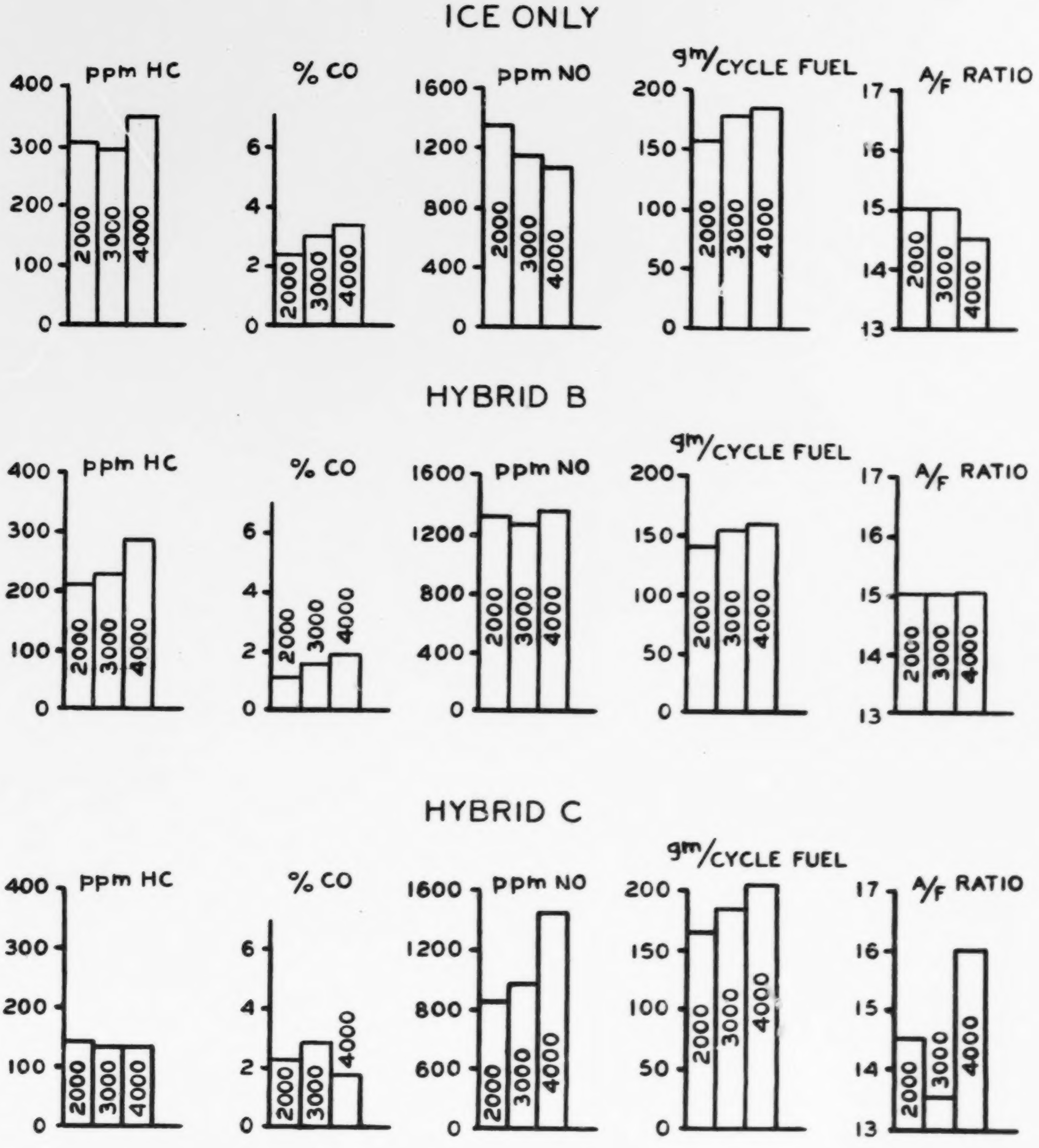


FIGURE 11 VEHICLE WEIGHT EFFECTS. CONCENTRATION EMISSION MEASUREMENTS WITH VEHICLE DRIVEN ON THE CALIFORNIA 7-MODE DRIVING CYCLE

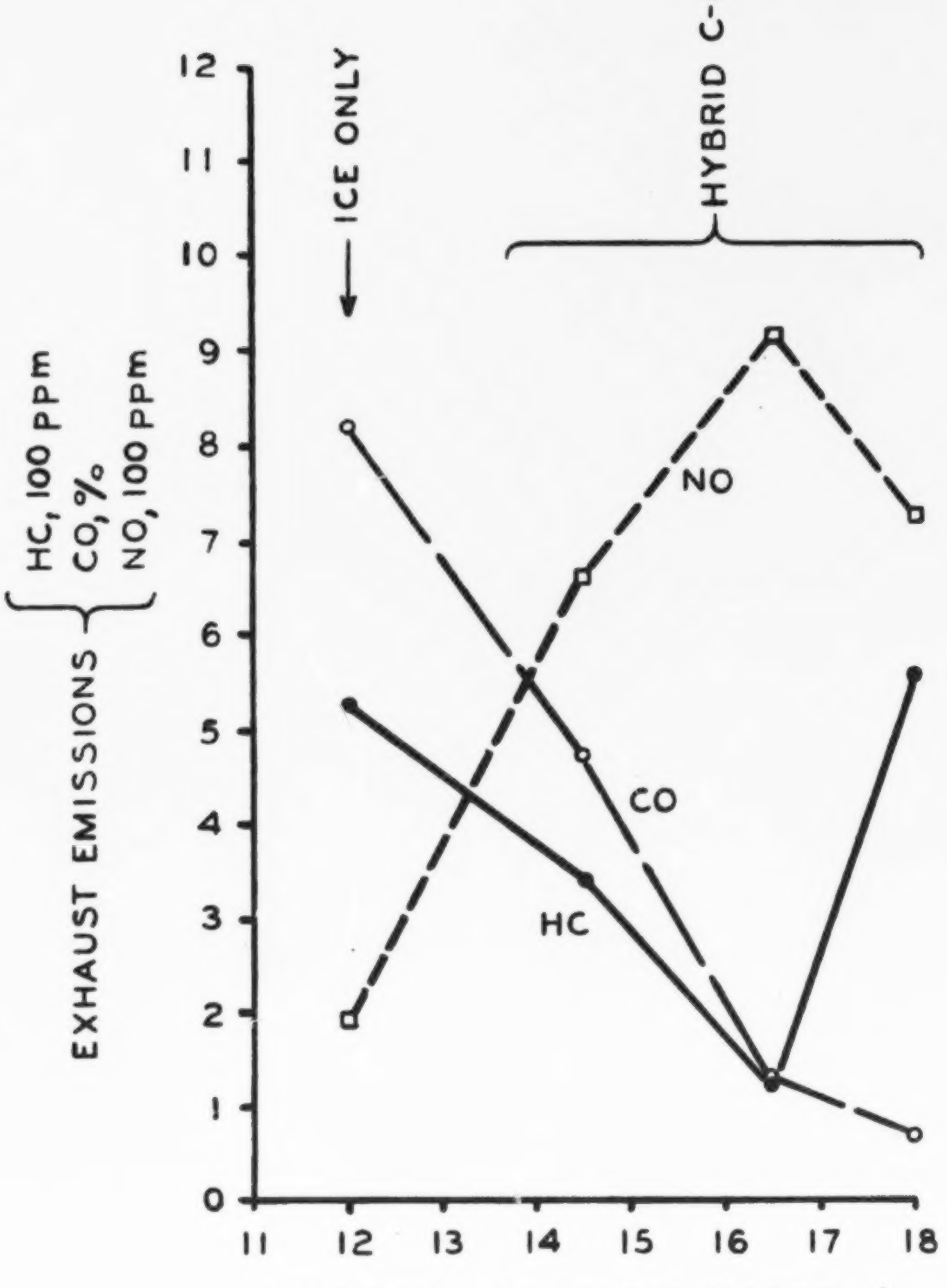


FIGURE 12 AIR/FUEL RATIO EFFECTS. CONCENTRATION MEASUREMENTS ON THE 7-MODE DRIVING CYCLE.

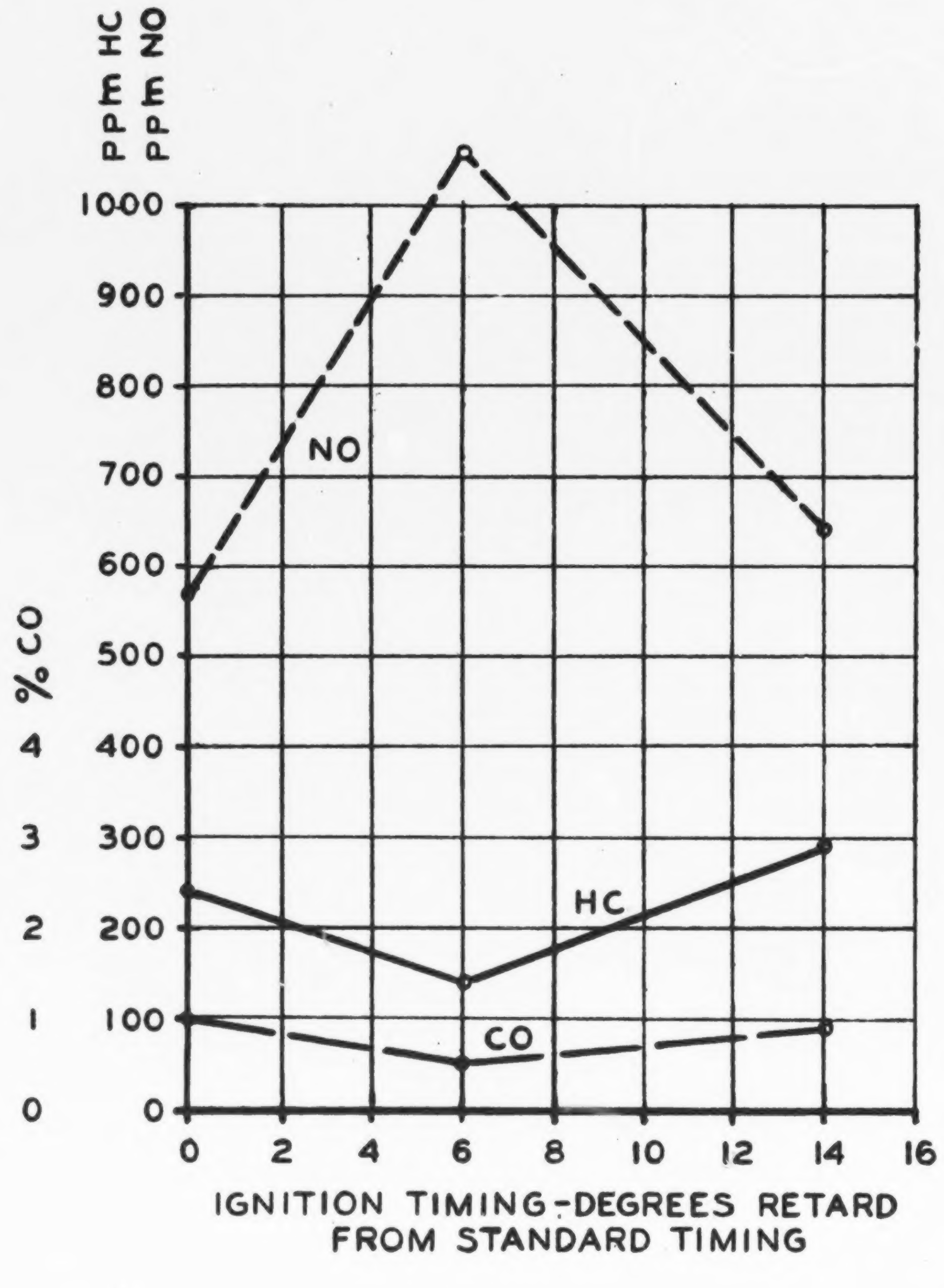


FIGURE 13 IGNITION TIMING EFFECTS. CONCENTRATION MEASUREMENTS ON 7-MODE DRIVING CYCLE.

POWER FOR 7-MODE CYCLE

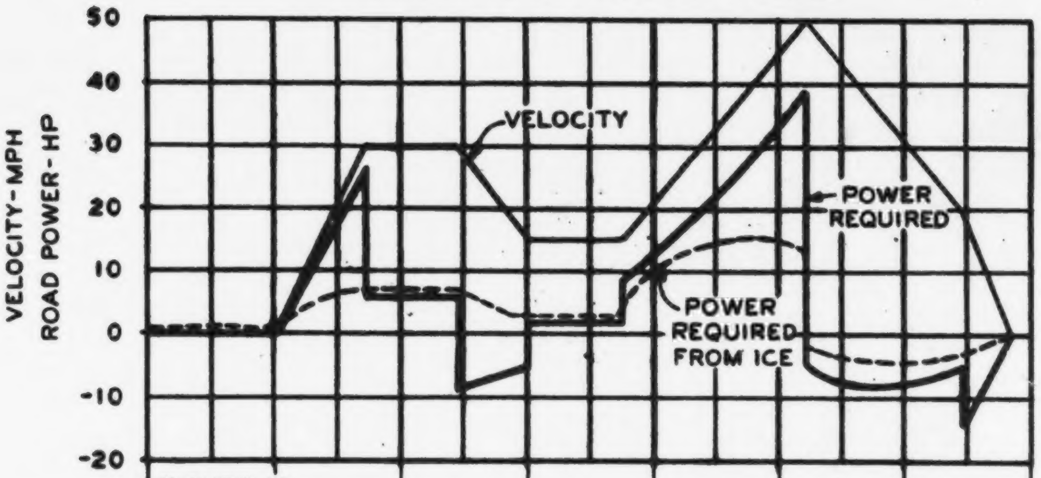


FIGURE 14

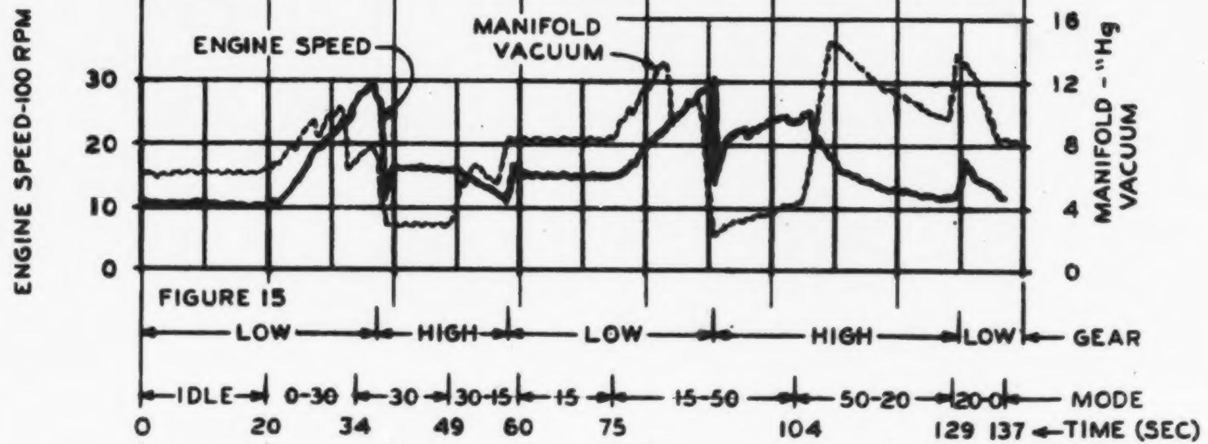


FIGURE 15

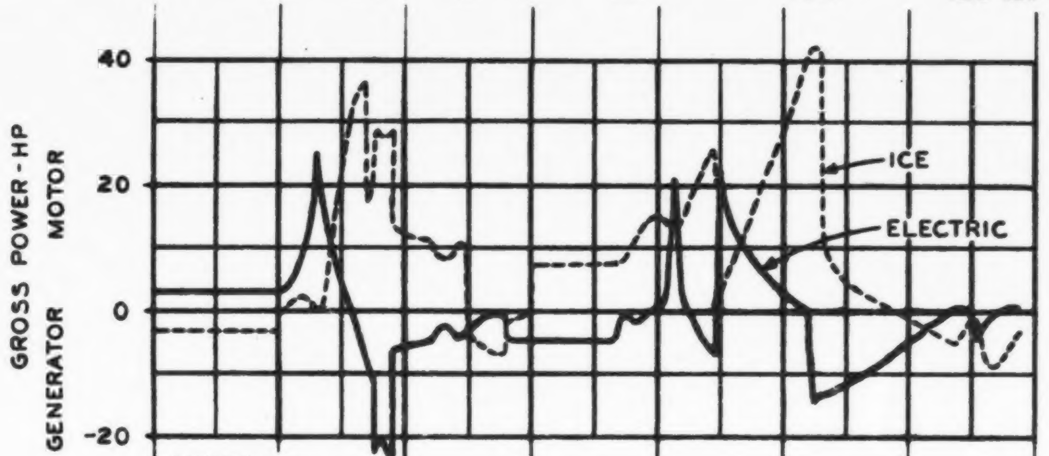


FIGURE 16

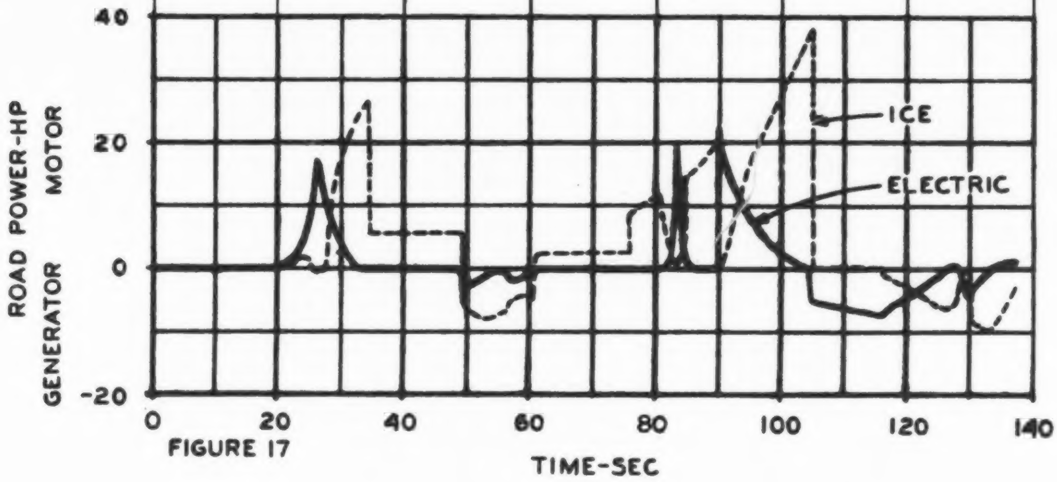


FIGURE 17

VII. APPENDIX

A. Vehicle Performance
B. California 7-Mode Power
C. Power Train Description
D. Test Procedures
E. Emission Measurement Log
F. Electrical Measurement Log
G. References

APPENDIX A

Vehicle Performance

Road Load Power Requirement

The power required for level road was estimated by using the following expression:[7]

$$P_{rl} = \frac{K_w WV}{375} + \frac{K_a AV^3}{375}$$

where P_{rl} = Road load power, hp

K_w = Coefficient of rolling resistance - .015

W = Weight of vehicle = 2,000, 3,000 and 4,000 lbs.

V = Velocity of vehicle, mph

K_a = Coefficient of air resistance = .00125

A = Frontal area of vehicle = 25 ft.^{2}

Power Available

Using the measured power available at the wheels of the Hybrid B vehicle power train, the curves shown in Figure A1 are derived. The level road power for 2,000, 3,000 and 4,000 pound weight vehicles are also shown in the same Figure.

Vehicle Acceleration

Acceleration of the vehicle can be calculated using:

$$a = \frac{375_g P_a}{VW}$$

where a = Acceleration, $\frac{\text{mph}}{\text{sec}}$

g = Gravity acceleration, $\frac{\text{mph}}{\text{sec}}$

V = Vehicle velocity, mph

W = Vehicle weight, lbs.

Converting the acceleration to an average acceleration over a small increment of vehicle speed, an elasped time can be calculated giving a velocity versus time diagram. These diagrams are shown in Figure A2 for the 2,000, 3,000 and 4,000 pound vehicles. The computations are shown in Tables AI, AII, and AIII.

HYBRID-B 2,000 LB

CAR VEL	POWER AVAIL	RL POWER	ACCEL POWER	MAX ACCEL	AVE ACCEL 5mph incr	DELTA TIME	TOTAL TIME
mph	hp	hp	hp	mph/sec	mph/sec	sec	sec
0	0	0	0	0			0
5	11	.4	10.6	8.74	9.0	.56	.56
10	21	.9	20.1	8.30	8.5	.59	1.15
15	29	1.5	27.5	7.55	7.9	.63	1.78
20	34	2.3	31.7	6.54	7.1	.70	2.48
25	37	3.3	33.7	5.55	6.1	.82	3.30
30	40	4.7	35.3	4.85	5.2	.96	4.26
35	43	6.4	36.6	4.31	4.6	1.09	5.35
40	45	8.5	36.5	3.77	4.0	1.25	6.60
45	45	11.2	33.8	3.10	3.4	1.47	8.07
50	44	14.4	29.6	2.44	2.8	1.79	9.86
55	43	18.2	24.8	1.86	2.2	2.27	12.13
60	46	22.8	22.2	1.53	1.7	2.94	15.07
65	49	27.5	21.5	1.37	1.4	3.57	18.64
70	51	34.1	16.9	1.00	1.2	4.17	22.81
75	51	41.1	9.9	.54	.8	6.25	29.06
80	50	48.9	1.1	.06	.3	16.64	45.70

TABLE AI

HYBRID-B 3,000 LB

CAR VEL	POWER AVAIL	RL POWER	ACCEL POWER	MAX ACCEL	AVE ACCEL 5mph incr	DELTA TIME	TOTAL TIME
mph	hp	hp	hp	mph/sec	mph/sec	sec	sec
0	0	0	0	0			0
5	11	.7	10.3	5.64	6.0	.83	.83
10	21	1.3	19.7	5.40	5.7	.88	1.71
15	29	2.0	27.0	4.93	5.2	.96	2.67
20	34	3.0	31.0	4.24	4.7	1.06	3.73
25	37	4.5	32.5	3.56	4.0	1.25	4.98
30	40	6.0	34.0	3.11	3.4	1.47	6.45
35	43	8.0	35.0	2.74	2.9	1.72	8.17
40	45	10.0	35.0	2.40	2.7	1.85	10.02
45	45	13.0	32.0	1.95	2.2	2.27	12.29
50	44	16.0	28.0	1.53	1.8	2.77	15.06
55	43	20.0	23.0	1.15	1.4	3.57	18.63
60	46	25.0	21.0	.96	1.1	4.53	23.16
65	49	30.0	19.0	.80	.9	5.55	28.71
70	51	37.0	14.0	.55	.7	7.15	35.86
75	51	44.0	7.0	.26	.5	10.00	45.86
80	50	52.0					

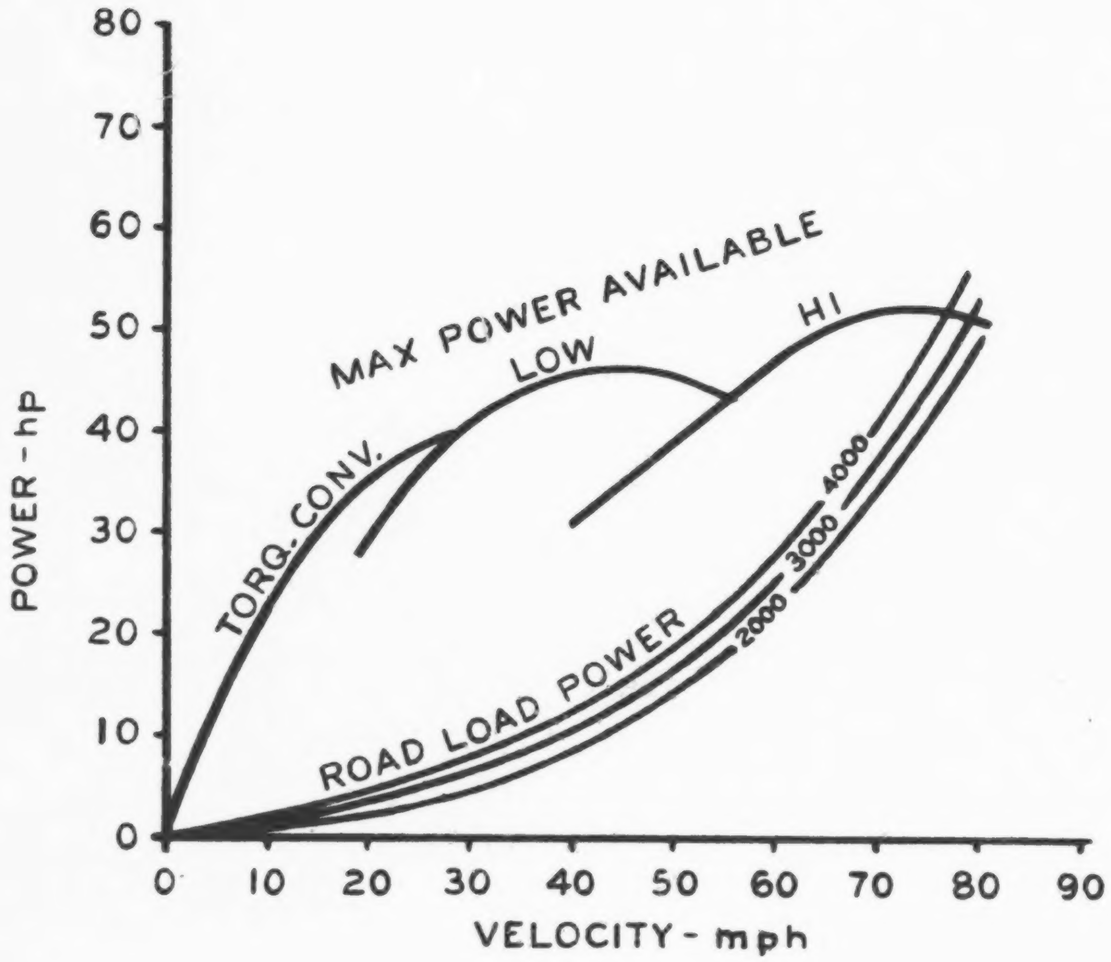
TABLE AII

HYBRID-B 4,000 LB

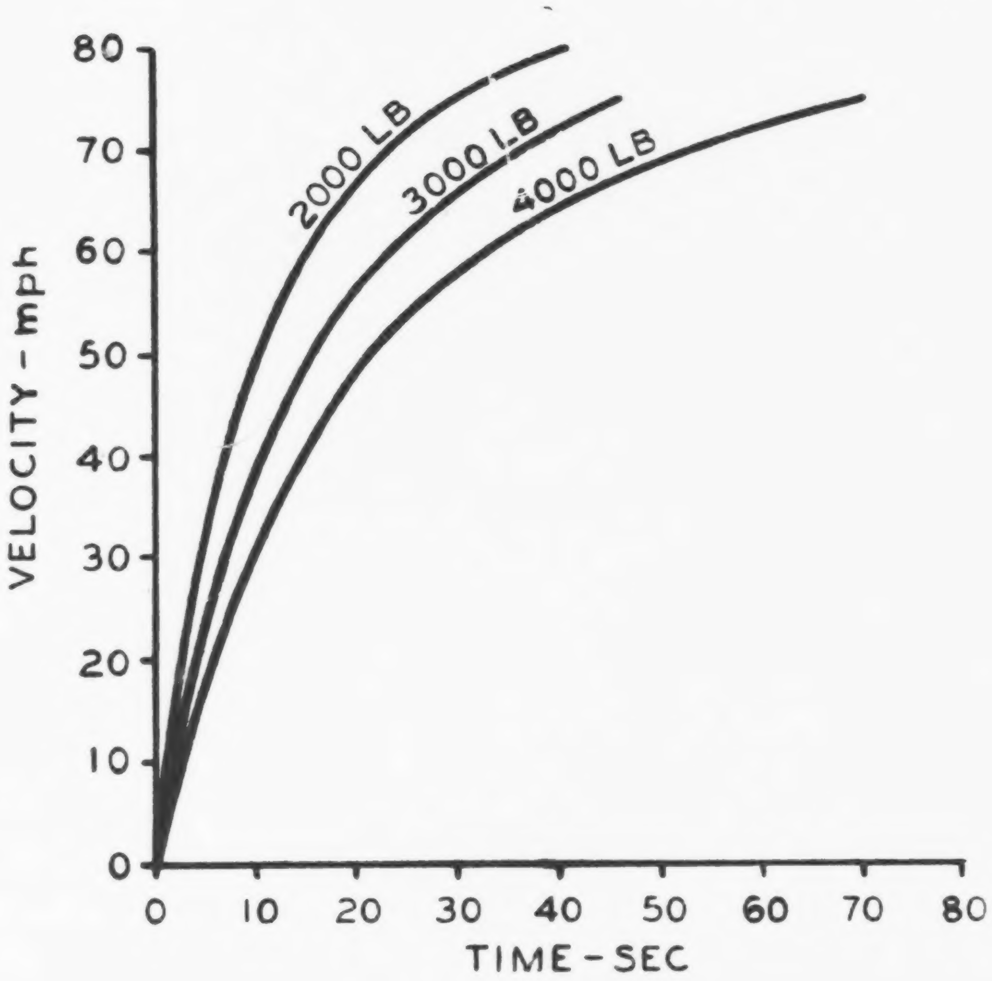
CAR VEL mph	POWER AVAIL hp	RL POWER hp	ACCEL POWER hp	MAX ACCEL mph/sec	AVE ACCEL 5mph incr mph/sec	DELTA TIME sec	TOTAL TIME sec
0	0	0	0	0			0
5	11	.8	10.2	4.20	4.4	1.13	1.13
10	21	1.7	19.3	3.98	4.1	1.22	2.35
15	29	2.7	26.3	3.61	3.8	1.32	3.67
20	34	3.9	30.1	3.10	3.4	1.47	5.14
25	37	5.3	31.7	2.61	2.9	1.72	6.86
30	40	7.0	33.0	2.27	2.4	2.08	8.94
35	43	9.2	33.8	1.99	2.2	2.27	11.21
40	45	11.7	33.3	1.71	1.9	2.63	13.84
45	45	14.8	30.2	1.38	1.6	3.12	16.96
50	44	18.4	25.6	1.05	1.3	3.85	20.81
55	43	22.6	20.4	.77	1.0	5.0	25.81
60	46	27.0	19.0	.65	.8	6.25	32.06
65	49	32.7	16.0	.51	.6	8.33	40.39
70	51	39.7	11.3	.33	.4	12.50	52.89
75	51	47.1	3.9	.11	.3	16.67	69.56
80	50	55.3					

TABLE AIII

HYBRID B 2000-3000-4000 LB WEIGHT



MAX. POWER AVAILABLE & ROAD LOAD POWER REQUIRED
FIGURE A-1



PERFORMANCE
FIGURE A-2

APPENDIX B

California 7-Mode Driving Cycle Power

Using the road load estimations made in the previous section on vehicle performance calculations, the power required to maintain a 2,000, 3,000 or 4,000 pound vehicle on the California 7-Mode Driving Cycle was computed. These Calculations are presented in Tables BI, BII, and BIII.

HYBRID-B 2,000 LB

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
0-20	0	0	0	0	0
21	2.17	2.17	1.142	.1735	1.3155
22	2.17	4.34	2.284	.354	2.638
23	2.17	6.51	3.34	.528	3.868
24	2.17	8.7	4.59	.751	5.341
25	2.17	10.8	5.7	1.015	6.715
26	2.17	13.0	6.86	1.215	8.075
27	2.17	15.2	8.02	1.425	9.485
28	2.17	17.35	9.25	1.821	10.071
29	2.17	19.5	10.28	2.179	12.459
30	2.17	21.7	11.42	2.585	14.005
31	2.17	23.8	12.55	3.03	15.58
32	2.0	26.0	12.63	3.545	16.175
33	2.0	28.0	13.6	4.075	17.675
34	2.0	30.0	14.6	4.65	19.25
34-49	0	30.0	0	4.65	4.65
49	-1.36	30.0	-9.94	4.65	-5.29
50	-1.36	28.6	-9.48	4.25	-5.23
51	-1.36	27.3	-9.05	3.88	-5.17
52	-1.36	25.9	-8.58	3.52	-5.06
53	-1.36	24.6	-8.15	3.21	-4.94
54	-1.36	23.2	-7.69	2.90	-4.79
55	-1.36	21.9	-7.25	2.63	-4.62
56	-1.36	20.5	-6.8	2.361	-4.44
57	-1.36	19.2	-6.36	1.970	-4.39
58	-1.36	17.8	-5.9	1.844	-4.144
59	-1.36	16.4	-5.34	1.68	-3.66
60	-1.36	15.0	-4.97	1.483	-3.49
60-75	0	15.0	0	1.483	1.483
75	1.2	15.0	4.38	1.483	5.863
76	1.2	16.2	4.73	1.649	6.379
77	1.2	17.4	5.08	1.832	6.912
78	1.2	18.6	5.43	2.023	7.453
79	1.2	19.8	5.78	2.235	8.015
80	1.2	21.0	6.13	2.456	8.586
81	1.2	22.2	6.49	2.688	9.178
82	1.2	23.4	6.83	2.94	9.77
83	1.2	24.6	7.19	3.21	10.40

TABLE BI

HYBRID-B 2,000 LB

Page 2

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
84	1.2	25.8	7.54	3.495	11.035
85	1.2	27.0	7.89	3.81	11.70
86	1.2	28.2	8.24	4.135	12.375
87	1.2	29.4	8.59	4.48	13.07
88	1.2	30.6	8.94	4.83	13.77
89	1.2	31.8	9.29	5.23	14.52
90	1.2	33.0	9.64	5.64	15.28
91	1.2	34.2	10.0	6.08	16.08
92	1.2	35.4	10.31	6.54	16.85
93	1.2	36.6	10.69	7.03	17.72
94	1.2	37.8	11.0	7.52	18.52
95	1.2	39.0	11.39	8.08	19.47
96	1.2	40.2	11.7	8.64	20.34
97	1.2	41.4	12.1	9.3	21.4
98	1.2	42.6	12.41	9.87	22.28
99	1.2	43.8	12.8	10.5	23.3
100	1.2	45.0	13.1	11.3	24.4
101	1.2	46.2	13.49	11.91	25.40
102	1.2	47.4	13.8	12.73	26.53
103	1.2	48.6	14.2	13.39	27.59
104	1.2	50.0	14.6	14.41	29.01
104	-1.2	50.0	-14.6	14.41	-.19
105	-1.2	48.8	-14.25	13.59	-.66
106	-1.2	47.6	-13.9	12.81	-1.09
107	-1.2	46.4	-13.52	12.04	-1.48
108	-1.2	45.2	-13.2	11.32	-1.88
109	-1.2	44.0	-12.82	10.62	-2.20
110	-1.2	42.8	-12.5	9.92	-2.58
111	-1.2	41.6	-12.12	9.32	-2.80
112	-1.2	40.4	-11.8	8.76	-3.04
113	-1.2	39.2	-11.42	8.18	-3.24
114	-1.2	38.0	-11.1	7.62	-3.48
115	-1.2	36.8	-10.72	7.11	-3.61
116	-1.2	35.6	-10.4	6.63	-3.77
117	-1.2	34.4	-10.05	6.16	-3.89
118	-1.2	33.2	-9.7	5.71	-3.99
119	-1.2	32.0	-9.35	5.30	-4.05
120	-1.2	30.8	-9.0	4.905	-4.09

TABLE BI

HYBRID-B 2,000 LB
Page 3

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
121	-1.2	29.6	-8.65	4.54	-4.11
122	-1.2	28.4	-8.3	4.19	-4.11
123	-1.2	27.2	-8.0	3.82	-4.18
124	-1.2	26.0	-7.59	3.549	-4.05
125	-1.2	24.8	-7.24	3.269	-3.971
126	-1.2	23.6	-6.89	2.990	-3.90
127	-1.2	22.4	-6.54	2.728	-3.812
128	-1.2	21.2	-6.19	2.49	-3.70
129	-1.2	20.0	-5.84	2.266	-3.58
129	-2.5	20.0	-12.15	2.266	-9.89
130	-2.5	17.5	-10.61	1.848	-8.76
131	-2.5	15.0	-9.11	1.482	-7.63
132	-2.5	12.5	-7.6	1.163	-6.563
133	-2.5	10.0	-6.08	.917	-5.16
134	-2.5	7.5	-4.55	.635	-3.91
135	-2.5	5.0	-3.04	.410	-2.63
136	-2.5	2.5	-1.52	.2	-1.32
137	-2.5	0	0	0	0

TABLE BI

HYBRID-B 3,000 LB

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
0-20	0	0	0	0	0
21	2.17	2.17	1.715	.259	1.974
22	2.17	4.34	3.32	.527	3.847
23	2.17	6.51	5.15	.781	5.93
24	2.17	8.7	6.87	1.10	7.97
25	2.17	10.8	8.54	1.45	9.99
26	2.17	13.0	10.25	1.735	11.985
27	2.17	15.2	12.0	2.03	14.03
28	2.17	17.35	13.7	2.516	16.22
29	2.17	19.5	15.4	2.959	18.36
30	2.17	21.7	17.1	3.45	20.55
31	2.17	23.8	18.8	3.98	22.78
32	2.0	26.0	18.9	4.58	23.48
33	2.0	28.0	20.4	5.19	25.59
34	2.0	30.0	21.8	5.85	27.65
34-49	0	30.0	0	5.85	5.85
49	-1.36	30.0	-14.85	5.85	-9.0
50	-1.36	28.6	-14.15	5.40	-8.75
51	-1.36	27.3	-13.5	4.97	-8.53
52	-1.36	25.9	-12.8	4.55	-8.25
53	-1.36	24.6	-12.2	4.20	-8.0
54	-1.36	23.2	-11.5	3.825	-7.675
55	-1.36	21.9	-10.85	3.50	-7.35
56	-1.36	20.5	-10.15	3.16	-6.99
57	-1.36	19.2	-9.5	2.735	-6.765
58	-1.36	17.8	-8.81	2.54	-6.27
59	-1.36	16.4	-8.13	2.33	-5.80
60	-13.6	15.0	-7.44	2.08	-5.36
60-75	0	15.0	0	2.08	2.08
75	-1.2	15.0	6.55	2.08	8.63
76	1.2	16.2	7.1	2.29	9.39
77	1.2	17.4	7.6	2.53	10.13
78	1.2	18.6	8.13	2.77	10.90
79	1.2	19.8	8.65	3.03	11.68
80	1.2	21.0	9.19	3.29	12.48
81	1.2	22.2	9.7	3.57	13.27
82	1.2	23.4	10.23	3.87	14.10
83	1.2	24.6	10.75	4.195	14.945

TABLE BII

HYBRID-B 3,000 LB

Page 2

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
84	1.2	25.8	11.2	4.52	15.72
85	1.2	27.0	11.8	4.89	16.69
86	1.2	28.2	12.3	5.26	17.56
87	1.2	29.4	12.85	5.66	18.51
88	1.2	30.6	13.4	6.06	19.46
89	1.2	31.8	13.9	6.50	20.40
90	1.2	33.0	14.4	6.96	21.36
91	1.2	34.2	14.95	7.46	22.41
92	1.2	35.4	15.5	7.96	23.46
93	1.2	36.6	16.0	8.5	24.5
94	1.2	37.8	16.5	9.03	25.03
95	1.2	39.0	17.05	9.64	26.69
96	1.2	40.2	17.6	10.25	27.85
97	1.2	41.4	18.1	10.95	29.05
98	1.2	42.6	18.6	11.58	30.18
99	1.2	43.8	19.1	12.25	31.25
100	1.2	45.0	19.7	13.1	32.8
101	1.2	46.2	20.2	13.71	33.91
102	1.2	47.4	20.7	15.63	36.33
103	1.2	48.6	21.2	15.44	36.64
104	1.2	50.0	21.9	16.41	38.31
104	-1.2	50.0	-21.9	16.41	-5.49
105	-1.2	48.8	-21.25	15.54	-5.71
106	-1.2	47.6	-20.76	14.71	-6.05
107	-1.2	46.4	-20.28	13.89	-6.39
108	-1.2	45.2	-19.8	13.13	-6.67
109	-1.2	44.0	-19.2	12.38	-6.82
110	-1.2	42.8	-18.7	11.635	-7.06
111	-1.2	41.6	-18.2	10,48	-7.22
112	-1.2	40.4	-17.7	10.38	-7.32
113	-1.2	39.2	-17.1	9.76	-7.44
114	-1.2	38.0	-16.6	8.76	-7.84
115	-1.2	36.8	-16.1	8.58	-7.52
116	-1.2	35.6	-15.6	8.05	-7.55
117	-1.2	34.4	-15.0	7.44	-7.56
118	-1.2	33.2	-14.5	7.04	-7.54
119	-1.2	32.0	-14.0	6.58	-7.42
120	-1.2	30.8	-13.5	6.13	-7.37

TABLE BII

HYBRID-B 3,000 LB

Page 3

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
121	-1.2	29.6	-12.9	5.73	-7.17
122	-1.2	28.4	-12.4	5.32	-7.08
123	-1.2	27.2	-11.9	4.91	-6.99
124	-1.2	26.0	-11.3	4.59	-6.71
125	-1.2	24.8	-10.8	4.25	-6.55
126	-1.2	25.6	-10.3	3.94	-6.36
127	-1.2	22.4	-9.8	3.62	-6.18
128	-1.2	21.2	-9.15	3.34	-5.81
129	-1.2	20.0	-8.7	3.06	-5.64
129	-2.5	20.0	-18.2	3.06	-15.14
130	-2.5	17.5	-15.9	2.55	-13.35
131	-2.5	15.0	-13.65	2.08	-11.57
132	-2.5	12.5	-11.39	1.66	-10.73
133	-2.5	10.0	-9.1	1.33	-7.77
134	-2.5	7.5	-6.82	.935	-5.88
135	-2.5	5.0	-4.55	.61	-3.94
136	-2.5	2.5	-2.28	.3	-1.98
137	-2.5	0	0	0	0

TABLE BII

HYBRID-B 4,000 LB

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
0-20	0	0	0	0	0
-21	2.17	2.17	2.284	.349	2.633
22	2.17	4.34	4.568	.401	4.969
23	2.17	6.51	6.68	1.033	7.71
24	2.17	8.7	9.18	1.45	10.63
25	2.17	10.8	11.4	1.88	13.28
26	2.17	13.0	13.72	2.26	15.98
27	2.17	15.2	16.04	1.64	17.68
28	2.17	17.35	18.50	3.21	21.71
29	2.17	19.5	20.56	3.74	24.30
30	2.17	21.7	22.84	4.32	27.16
31	2.17	23.8	25.10	4.93	30.03
32	2.0	26.0	25.26	5.63	30.89
33	2.0	28.0	27.2	6.32	33.52
34	2.0	30.0	29.2	6.73	35.93
34-49	0	30.0	0	6.73	6.73
49	-1.36	30.0	-19.88	6.73	-13.15
50	-1.36	28.6	-18.96	6.54	-12.42
51	-1.36	27.3	-18.10	6.06	-12.04
52	-1.36	25.9	-17.16	5.59	-11.57
53	-1.36	24.6	-16.30	5.18	-11.12
54	-1.36	25.2	-15.38	4.75	-10.63
55	-1.36	21.9	-14.50	4.38	-10.12
56	-1.36	20.5	-13.6	4.0	-9.6
57	-1.36	19.2	-12.72	3.51	-9.21
58	-1.36	17.8	-11.8	3.24	-8.56
59	-1.36	16.4	-10.68	2.99	-7.69
60	-1.36	13.0	-9.94	2.68	-7.26
60-75	0	15.0	0	2.68	2.68
75	1.2	15.0	8.76	2.68	11.44
76	1.2	16.2	9.46	2.94	12.40
77	1.2	17.4	10.16	3.22	13.38
78	1.2	18.6	10.86	3.51	14.37
79	1.2	19.8	11.56	3.82	15.38
80	1.2	21.0	12.26	4.14	16.40
81	1.2	22.2	12.98	4.46	17.44
82	1.2	23.4	13.66	4.81	18.47
83	1.2	24.6	14.38	5.18	19.56

TABLE BIII

HYBRID-B 4,000 LB

Page 2

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
84	1.2	25.8	15.08	5.55	20.63
85	1.2	27.0	15.78	5.97	21.75
86	1.2	28.2	16.48	6.40	22.88
87	1.2	29.4	17.18	6.83	24.01
88	1.2	30.6	17.88	7.28	25.16
89	1.2	31.3	18.58	7.77	26.35
90	1.2	33.0	19.28	8.28	27.56
91	1.2	34.2	20.0	8.82	28.82
92	1.2	35.4	20.62	9.37	29.99
93	1.2	36.6	21.38	9.96	31.34
94	1.2	37.8	22.0	10.54	32.54
95	1.2	39.0	22.78	11.20	33.98
96	1.2	40.2	23.4	11.86	35.26
97	1.2	41.4	24.2	12.6	36.8
98	1.2	42.6	24.81	13.28	38.09
99	1.2	43.8	25.6	14.0	39.6
100	1.2	45.0	26.2	14.9	41.1
101	1.2	46.2	26.98	15.61	42.59
102	1.2	47.4	27.6	16.53	44.13
103	1.2	48.6	28.4	17.38	45.78
104	1.2	50.0	29.2	18.41	47.61
104	-1.2	50.0	-29.2	18.41	-10.79
105	-1.2	48.8	-28.5	17.49	-11.01
106	-1.2	47.6	-27.8	16.62	-11.18
107	-1.2	46.4	-27.04	15.74	-12.30
108	-1.2	45.2	-26.4	14.98	-11.42
109	-1.2	44.0	-25.64	14.14	-11.50
110	-1.2	42.8	-25.0	13.30	-11.61
111	-1.2	41.6	-24.24	12.64	-11.60
112	-1.2	40.4	-23.6	11.99	-11.61
113	-1.2	39.2	-22.84	11.32	-11.52
114	-1.2	38.0	-22.14	10.70	-11.44
115	-1.2	36.8	-21.44	10.06	-11.38
116	-1.2	35.6	-20.8	9.48	-11.32
117	-1.2	34.4	-20.10	8.91	-11.19
118	-1.2	33.2	-19.4	8.37	-11.03
119	-1.2	32.0	-18.7	7.86	-10.84
120	-1.2	30.8	-18.0	7.37	-10.63

TABLE BIII

HYBRID-B 4,000 LB

Page 3

TIME (sec)	ACCEL (mph/sec)	VELOCITY (mph)	ACCEL POWER (hp)	ROAD LOAD POWER (hp)	TOTAL POWER (hp)
121	-1.2	29.6	-17.3	6.91	-10.39
122	-1.2	28.4	-16.6	6.46	-10.14
123	-1.2	27.2	-16.0	6.00	-10.00
124	-1.2	26.0	-15.18	5.63	-9.55
125	-1.2	24.8	-14.48	5.26	-9.22
126	-1.2	23.6	-13.78	4.88	-8.90
127	-1.2	22.4	-13.08	4.52	-8.56
128	-1.2	21.2	-12.38	4.19	-8.19
129	-1.2	20.0	-11.68	3.87	-7.81
129	-2.5	20.0	-24.30	3.87	-20.43
130	-2.5	17.5	-21.22	3.25	-17.97
131	-2.5	15.0	-18.22	2.68	-15.54
132	-2.5	12.5	-15.2	2.16	-13.04
133	-2.5	10.0	-12.16	1.75	-10.41
134	-2.5	7.5	-9.10	1.24	-7.86
135	-2.5	5.0	-6.08	.81	-5.27
136	-2.5	2.5	-3.04	.4	-2.64
137	-2.5	0	0	0	0

TABLE BIII

APPENDIX C

Power Train Description

ICE Only Power Train

Mechanical:

- 164 cu. in. displacement Corvair engine, 8.5 to 1 compression ratio
- Single venturi carburetor 1-9/16" diameter
  Choke
  Heated intake air
  Accelerator pump
  .062 main jet, idle jet, power jet
- Single carburetor manifold, 1-3/4" diameter legs
- Two-speed automatic transmission
  Low gear, 1.83 to 1
  High gear, 1 to 1
  Torque converter, 2 to 1
  Shift points, 30 mph up, 24 mph down on 7-mode cycle

Electrical:

- Electric machine is mechanically coupled and turning, but electrically is disconnected.
- Electric machine is used as a starter for the ICE.

Hybrid B Power Train

Mechanical:

- Engine and carburetor same as described for ICE only power train, except no choke and no accelerator pump used in carburetor.
- Same transmission

Electrical:

- Motor/generator G22-3, Lear Siegler, 24V, 300 amp, 9.7 hp rated shunt machine, 94 lb. weight, 2,000 to 6,500 rpm range.
- Batteries: 24V system, 400 AH consisting of 4 to 6V, heavy duty industrial lead-acid batteries in the front of the vehicle (200 lbs.) and 4 to 12V SLI batteries in the rear of the vehicle (200 lbs.), as shown in Figure C2. Total battery weight is 400 lbs.
- Bang-bang control system, field control modulation via a vacuum switch activated by the intake manifold depression.

As an example of the vacuum actuated controller, consider the three-step system (see Figure C1).

The operation of the motor is controlled by the manifold vacuum from the engine. As the driver depresses the accelerator pedal, the engine load increases and as a consequence, the amount of manifold vacuum decreases. Vacuum switch 1 (VS-1), senses the drop of manifold depression to less than 9"Hg and activates R-1, a relay which shifts from generator mode to motor mode. The current to the shunt field is still fully supplied through R-2 and R-3. As the vacuum continues to drop at 7"Hg vacuum, switch 2 (VS-2) activates R-2, introducing a resistance in series with the shunt field and decreasing the field current. This decrease causes an inrush of armature current since a lower field current implies a reduced counter EMF. The electric machine operates now in the motor mode supplying between 5 and 10 hp to the drive train. If the manifold vacuum drops farther, vacuum switch 3 (VS-3) activates R-3 and the larger resistance is introduced in series with the shunt field. The field current is now minimal causing a large armature current and as a consequence, the motor delivers between 10 to 15 ($\times \eta$ %) hp to the drive train. Note that the field current should never be completely reduced to "0". Since the machine used is of the shunt type, and the torque equals $T = KI_AI_F$, if I_F is "0", even a large I_A will not be beneficial.

As soon as the vehicle is past the acceleration cycle and the engine is capable of supplying the road load, the manifold vacuum increases above 10"Hg causing R-1 to switch the field back from its motor mode into the generator mode. In this condition and with SW-1 in the normal position, the field of the electric machine is connected directly into a carbon pile type voltage regulator which controls the rate of charging current into the batteries. SW-1 can also be used as a manual control to induce operation of the machine in the motor mode for testing purposes.

Hybrid C Power Train

Mechanical:

- Engine and carburetor is the same as described for ICE only power train, except no choke and no accelerator pump is used in the carburetor. Also, a delay mechanism is used in the throttle control.
- Same transmission.

Electrical:

- Motor/generator is the same as described for Hybrid B system, but modulated with both shunt field control and variable armature voltage.
- Batteries: 24/48V system, 600/300 AH as shown in Figure C2(200 lbs. in front, 200 lbs. in the rear and 240 lbs. on side, which gives a total of 640 lbs.).
- Electrical control system consists of a motor/generator switching circuit, 24/48V switching circuit and field driven amplifier as shown in Figures C3, C4, and C5, respectively.

Hybrid C-1 Power Train

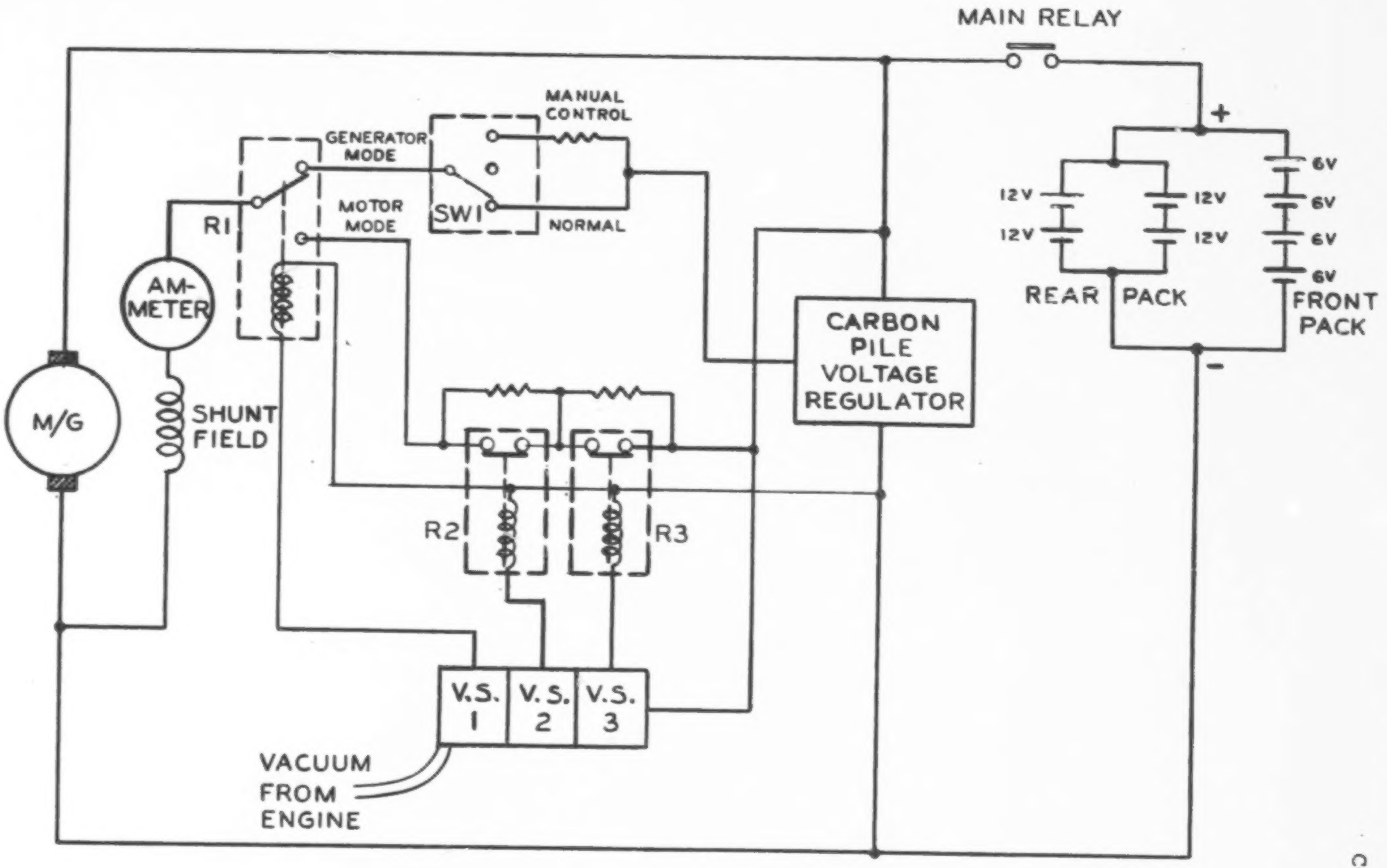
- Same as Hybrid C, except that the intake manifold legs were reduced to 1" diameter and exhaust gas is used for manifold heating.

ICE Spark Advance

The distributor advance mechanism provides the following spark advances for the engine:

ENGINE SPEED (rpm)	SPARK ADVANCE (Deg. BTC)
800	12
1200	14
1600	17
2000	19
2400	21
2800	26
3200	30

Vacuum spark advance in 15 to 20 degrees advance.



HYBRID B -
BASIC ELECTRICAL SYSTEM

FIGURE C-1

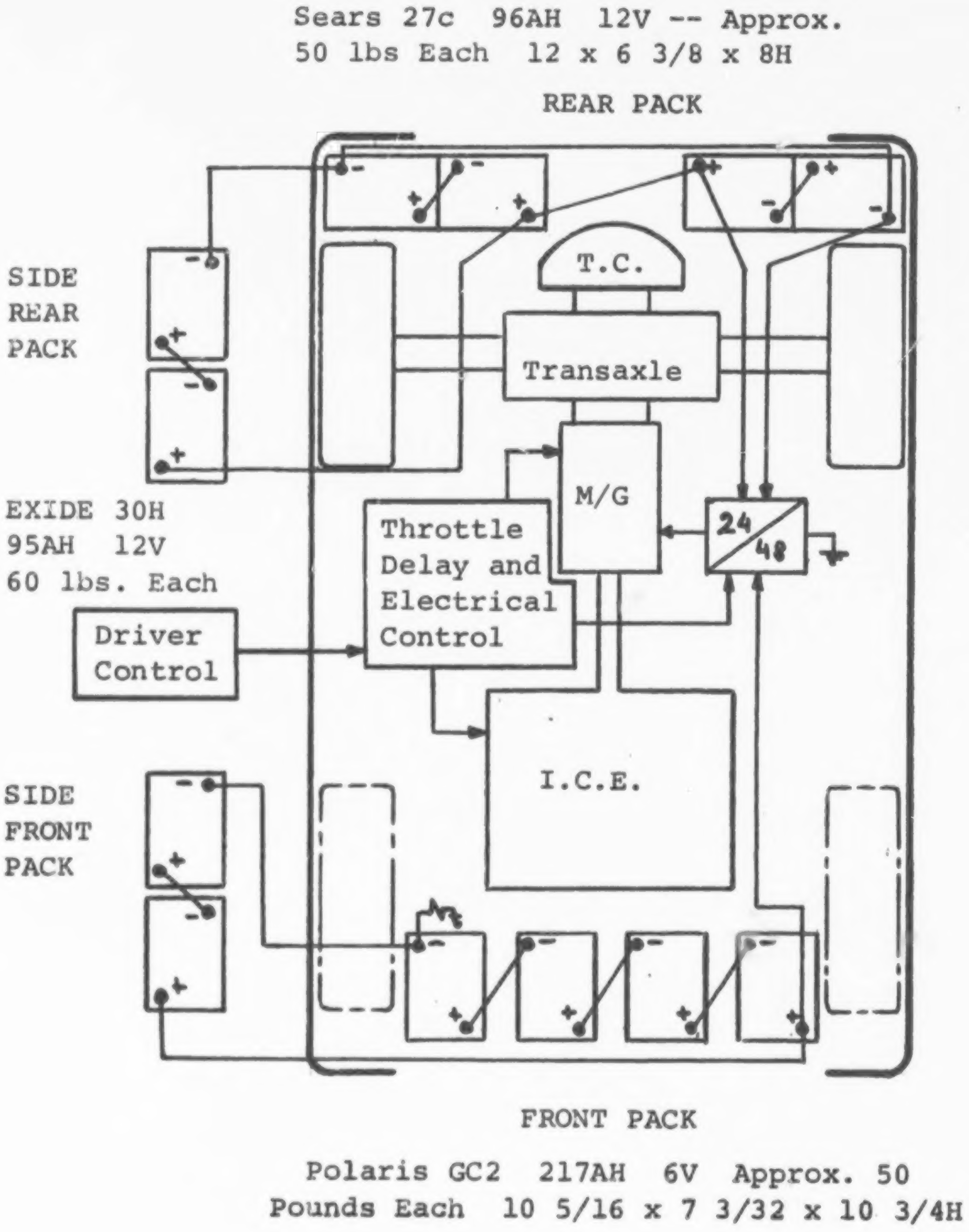
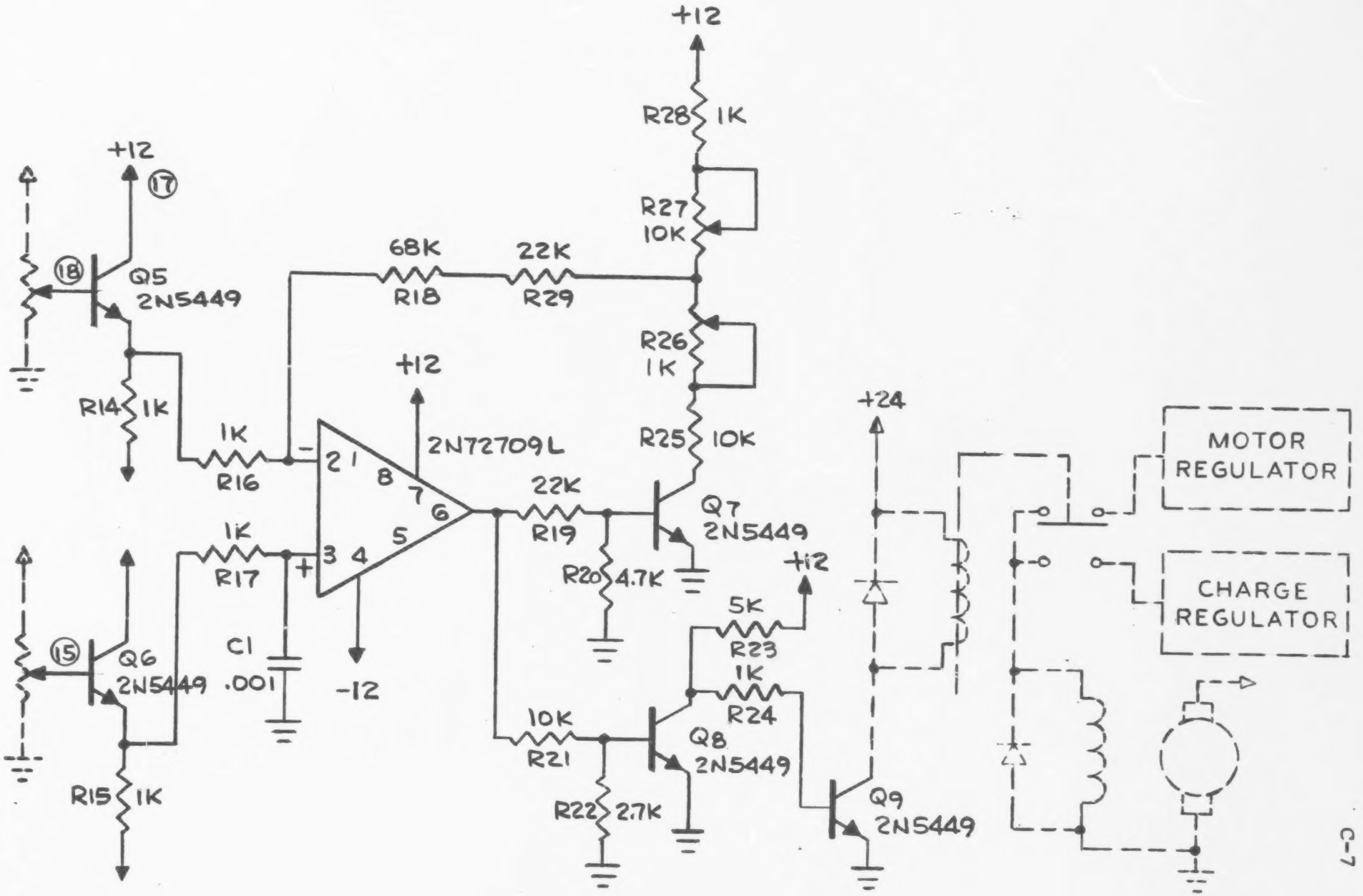
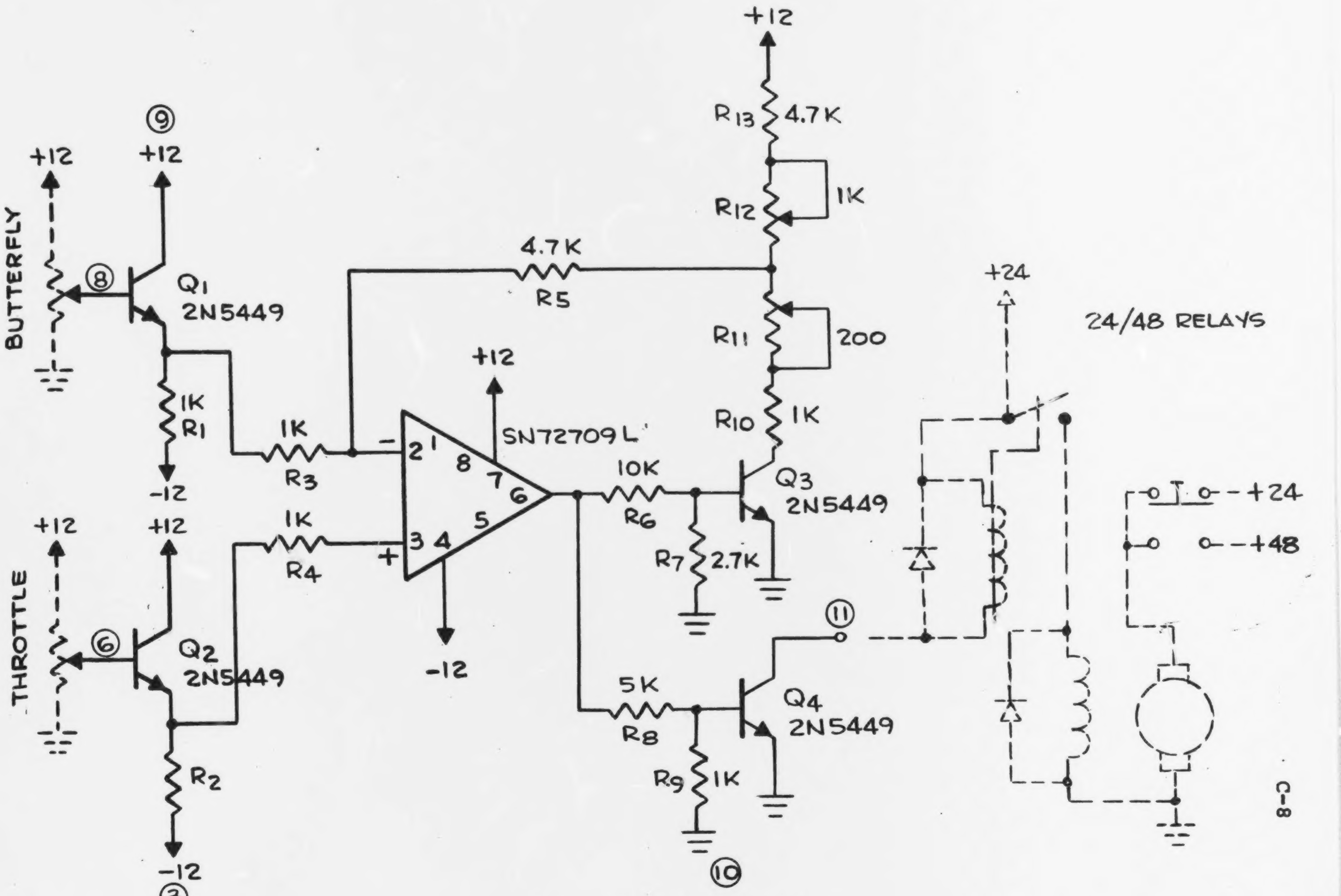

Sears 27c 96AH 12V -- Approx.
50 lbs Each 12 x 6 3/8 x 8H
REAR PACK
SIDE REAR PACK
T.C.
Transaxle
M/G
24/48
Throttle Delay and Electrical Control
EXIDE 30H
95AH 12V
60 lbs. Each
Driver Control
I.C.E.
SIDE FRONT PACK
FRONT PACK
Polaris GC2 217AH 6V Approx. 50
Pounds Each 10 5/16 x 7 3/32 x 10 3/4H

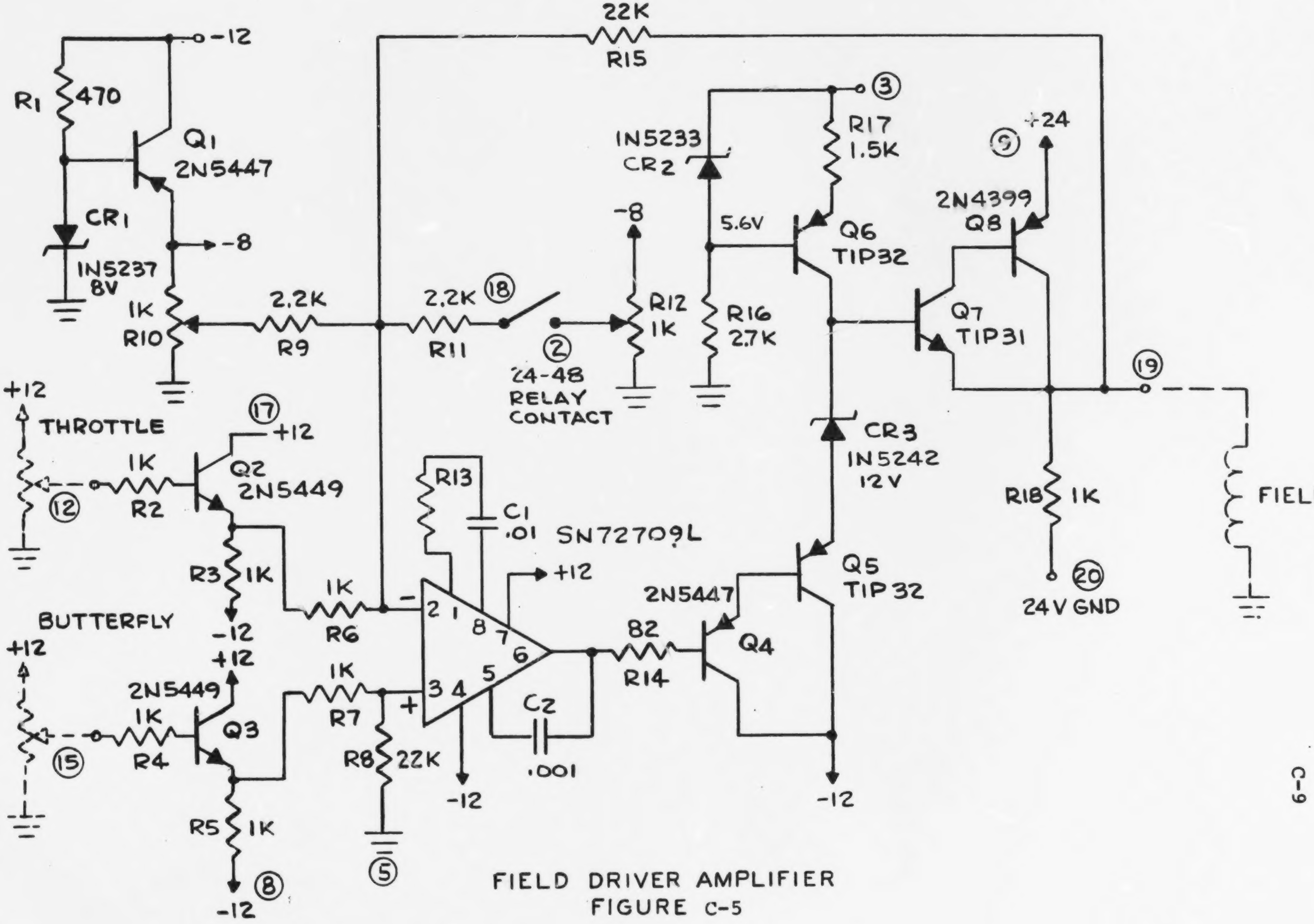
FIGURE C-2 BATTERY PACK CONFIGURATION - Hybrid C



MOTOR/GENERATOR SWITCHING CIRCUIT
FIGURE C-3



24/48 SWITCHING CIRCUIT
FIGURE C-4



FIELD DRIVER AMPLIFIER
FIGURE C-5

APPENDIX D

California and Federal test procedures for vehicle exhaust emissions.

INTRODUCTION

The following procedure was used in the testing program to determine exhaust emission:

(1) The test consists of prescribed sequences of vehicle operating conditions on a chassis dynamometer. The exhaust gases generated during vehicle operation are sampled continuously for specific component analysis through the analytical train.

(2) The basic exhaust emission test is designed to determine hydrocarbon, carbon monoxide and oxides of nitrogen concentrations while simulating an averate trip in a metropolitan area.

GASOLINE FUEL

Indolene-30 gasoline was used for all the dynamometer testing.

DYNAMOMETER OPERATION CYCLE

The California 7-mode and the Federal DHEW driving cycle dynamometer tests were used for the emission tests. These tests are described as follows:

CALIFORNIA 7-MODE DRIVING CYCLE[4]

Sequence Number	Mode No.	Cycle mph	Time sec.	Cumulative Time sec.	Weighting Factor
1	1	Idle	20	20.0	.042
2	2	0-25	11.5	31.5	.244
3		25-30	2.5	34.0	*
4	3	30	15.0	49.0	.118
5	4	30-15	11.0	60.0	.062
6	5	15	15.0	75.0	.050
7	6	15-30	12.5	87.5	.455
8		30-50	16.5	104.0	*
9	7	50-20	25.0	129.0	.029
10		20-0	8.0	137.0	*

*Data not read.

Sampling and analytical system for the exhaust emissions are described in Federal Register of 4 June 1968.

The concentration measurements for the California 7-mode driving cycle are made only during 7 of the actual 10 sequences of driving in the cycle. Figure D-1 shows the measurement modes. Note that the 25-30 mph acceleration and 30-50 mph accelerations are not measured. Neither is the deceleration from 20-0 mph. The CVS type measurement on the other hand measures all the emissions for the total driving cycle for both the 7-mode and DHEW driving cycles.

A chassis dynamometer equipped with a power absorption unit and a flywheel inertia weight of 3,000 pounds was used to provide vehicle road loading. Some tests were also run with 2,000 and 4,000 pound flywheels. The vehicle was in a level position to prevent unusual fuel distribution. A cooling fan was positioned in the rear of the vehicle and the dynamometer runs were made with hood up.

Automatic Transmissions

1. All test conditions were run with the transmission in "drive" (highest gear).

2. Idle: Idle was run with the transmission in "drive" and the wheels braked.

3. Cruise: The vehicle was driven at constant throttle position to maintain specified speed in highest gear.

4. Accelerations: Modes were run at nearly constant accelerations, allowing the transmission to shift automatically through the normal sequence of gears.

5. Decelerations: These modes were run at closed throttle maintaining a constant deceleration by using the vehicle brakes.

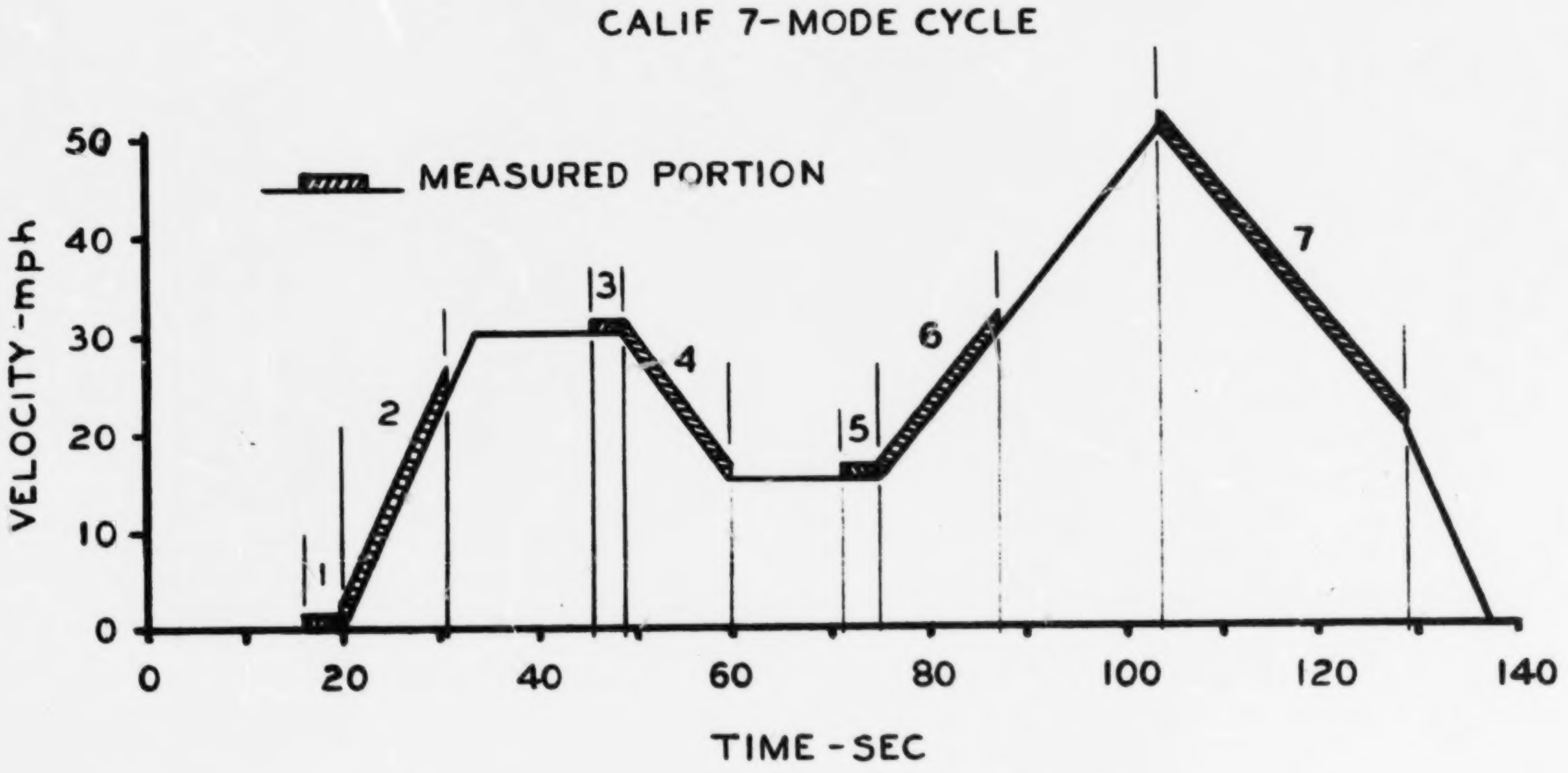

CALIF 7-MODE CYCLE
MEASURED PORTION
VELOCITY-mph
0
10
20
30
40
50
TIME-SEC
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7

FIGURE D-1

FEDERAL DHEW DRIVING CYCLE[6]

DHEW URBAN DYNAMOMETER DRIVING SCHEDULE

(Speed versus Time Sequence)

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
0	0.0	84	28.6	168	16.5
1	0.0	85	29.3	169	19.8
2	0.0	86	29.8	170	22.2
3	0.0	87	30.1	171	24.3
4	0.0	88	30.4	172	25.8
5	0.0	89	30.7	173	26.4
6	0.0	90	30.7	174	25.7
7	0.0	91	30.5	175	25.1
8	0.0	92	30.4	176	24.7
9	0.0	93	30.3	177	25.0
10	0.0	94	30.4	178	25.2
11	0.0	95	30.8	179	25.4
12	0.0	96	30.4	180	25.8
13	0.0	97	29.9	181	27.2
14	0.0	98	29.5	182	26.5
15	0.0	99	29.8	183	24.0
16	0.0	100	30.3	184	22.7
17	0.0	101	30.7	185	19.4
18	0.0	102	30.9	186	17.7
19	0.0	103	31.0	187	17.2
20	0.0	104	30.9	188	18.1
21	3.0	105	30.4	189	18.6
22	5.9	106	29.8	190	20.0
23	8.6	107	29.9	191	22.2
24	11.5	108	30.2	192	24.5
25	14.3	109	30.7	193	27.3
26	16.9	110	31.2	194	30.5
27	17.3	111	31.8	195	33.5
28	18.1	112	32.2	196	36.2
29	20.7	113	32.4	197	37.3
30	21.7	114	32.2	198	39.3
31	22.4	115	31.7	199	40.5
32	22.5	116	28.6	200	42.1
33	22.1	117	25.3	201	43.5
34	21.5	118	22.0	202	45.1
35	20.9	119	18.7	203	46.0
36	20.4	120	15.4	204	46.8
37	19.8	121	12.1	205	47.5
38	17.0	122	8.8	206	47.5
39	14.9	123	5.5	207	47.3
40	14.9	124	2.2	208	47.2
41	15.2	125	0.0	209	47.0
42	15.5	126	0.0	210	47.0
43	16.0	127	0.0	211	47.0
44	17.1	128	0.0	212	47.0
45	19.1	129	0.0	213	47.0
46	21.1	130	0.0	214	47.2
47	22.7	131	0.0	215	47.4
48	22.9	132	0.0	216	47.9
49	22.7	133	0.0	217	48.5
50	22.6	134	0.0	218	49.1
51	21.3	135	0.0	219	49.5
52	19.0	136	0.0	220	50.0
53	17.1	137	0.0	221	50.6
54	15.8	138	0.0	222	51.0
55	15.8	139	0.0	223	51.5
56	17.7	140	0.0	224	52.2
57	19.8	141	0.0	225	53.2
58	21.6	142	0.0	226	54.1
59	23.2	143	0.0	227	54.6
60	24.2	144	0.0	228	54.9
61	24.6	145	0.0	229	55.0
62	24.9	146	0.0	230	54.9
63	25.0	147	0.0	231	54.6
64	24.6	148	0.0	232	54.6
65	24.5	149	0.0	233	54.8
66	24.7	150	0.0	234	55.1
67	24.8	151	0.0	235	55.5
68	24.7	152	0.0	236	55.7
69	24.6	153	0.0	237	56.1
70	24.6	154	0.0	238	56.3
71	25.1	155	0.0	239	56.6
72	25.6	156	0.0	240	56.7
73	25.7	157	0.0	241	56.7
74	25.4	158	0.0	242	56.5
75	24.9	159	0.0	243	56.5
76	25.0	160	0.0	244	56.5
77	25.4	161	0.0	245	56.5
78	26.0	162	0.0	246	56.5
79	26.0	163	0.0	247	56.5
80	25.7	164	3.3	248	56.4
81	26.1	165	6.6	249	56.1
82	26.7	166	9.9	250	55.8
83	27.5	167	13.2	251	55.1

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
252	54.6	339	0.0	426	8.5	513	5.5	600	21.6	686	0.0
253	54.2	340	0.0	427	5.2	514	6.5	601	22.0	687	0.0
254	54.0	341	0.0	428	1.9	515	8.5	602	22.4	688	0.0
255	53.7	342	0.0	429	0.0	516	9.6	603	22.5	689	0.0
256	53.6	343	0.0	430	0.0	517	10.5	604	22.5	690	0.0
257	53.9	344	0.0	431	0.0	518	11.9	605	22.5	691	0.0
258	54.0	345	0.0	432	0.0	519	14.0	606	22.7	692	0.0
259	54.1	346	0.0	433	0.0	520	16.0	607	23.7	693	0.0
260	54.1	347	1.0	434	0.0	521	17.7	608	25.1	694	1.4
261	53.8	348	4.3	435	0.0	522	19.0	609	26.0	695	3.3
262	53.4	349	7.6	436	0.0	523	20.1	610	26.5	696	4.4
263	53.0	350	10.9	437	0.0	524	21.0	611	27.0	697	6.5
264	52.6	351	14.2	438	0.0	525	22.0	612	26.1	698	9.2
265	52.1	352	17.3	439	0.0	526	23.0	613	22.3	699	11.3
266	52.4	353	20.0	440	0.0	527	23.8	614	19.5	700	13.5
267	52.0	354	22.5	441	0.0	528	24.5	615	16.2	701	14.6
268	51.9	355	23.7	442	0.0	529	24.9	616	12.9	702	16.4
269	51.7	356	25.2	443	0.0	530	25.0	617	9.6	703	16.7
270	51.5	357	26.6	444	0.0	531	25.0	618	6.3	704	16.5
271	51.6	358	28.1	445	0.0	532	25.0	619	3.0	705	16.5
272	51.8	359	30.0	446	0.0	533	25.0	620	0.0	706	18.2
273	52.1	360	30.8	447	0.0	534	25.0	621	0.0	707	19.2
274	52.5	361	31.6	448	3.3	535	25.0	622	0.0	708	20.1
275	53.0	362	32.1	449	6.6	536	25.6	623	0.0	709	21.5
276	53.5	363	32.8	450	9.9	537	25.8	624	0.0	710	22.5
277	54.0	364	33.6	451	13.2	538	26.0	625	0.0	711	22.5
278	54.9	365	34.5	452	16.5	539	25.6	626	0.0	712	22.1
279	55.4	366	34.6	453	19.8	540	25.2	627	0.0	713	22.7
280	55.6	367	34.9	454	23.1	541	25.0	628	0.0	714	23.3
281	56.0	368	34.8	455	26.4	542	25.0	629	0.0	715	23.5
282	56.0	369	34.5	456	27.8	543	25.0	630	0.0	716	22.5
283	55.8	370	34.7	457	29.1	544	24.4	631	0.0	717	21.6
284	55.2	371	35.5	458	31.5	545	23.1	632	0.0	718	20.5
285	54.5	372	36.0	459	33.0	546	19.8	633	0.0	719	18.0
286	53.6	373	36.0	460	33.6	547	16.5	634	0.0	720	15.0
287	52.5	374	36.0	461	34.8	548	13.2	635	0.0	721	12.0
288	51.5	375	36.0	462	35.1	549	9.9	636	0.0	722	9.0
289	51.5	376	36.0	463	35.6	550	6.6	637	0.0	723	6.2
290	51.5	377	36.0	464	36.1	551	3.3	638	0.0	724	4.5
291	51.1	378	36.1	465	36.0	552	0.0	639	0.0	725	3.0
292	50.1	379	36.4	466	36.1	553	0.0	640	0.0	726	2.1
293	50.0	380	36.5	467	36.2	554	0.0	641	0.0	727	0.5
294	50.1	381	36.4	468	36.0	555	0.0	642	0.0	728	0.5
295	50.0	382	36.0	469	35.7	556	0.0	643	0.0	729	3.2
296	49.6	383	35.1	470	36.0	557	0.0	644	0.0	730	6.5
297	49.5	384	34.1	471	36.0	558	0.0	645	0.0	731	9.6
298	49.5	385	33.5	472	35.6	559	0.0	646	2.0	732	12.5
299	49.5	386	31.4	473	35.5	560	0.0	647	4.5	733	14.0
300	49.1	387	29.0	474	35.4	561	0.0	648	7.8	734	16.0
301	48.6	388	25.7	475	35.2	562	0.0	649	10.2	735	18.0
302	48.1	389	23.0	476	35.2	563	0.0	650	12.5	736	19.6
303	47.2	390	20.3	477	35.2	564	0.0	651	14.0	737	21.5
304	46.1	391	17.5	478	35.2	565	0.0	652	15.3	738	23.1
305	45.0	392	14.5	479	35.2	566	0.0	653	17.5	739	24.5
306	43.8	393	12.0	480	35.2	567	0.0	654	19.6	740	25.5
307	42.6	394	8.7	481	35.0	568	0.0	655	21.0	741	26.5
308	41.5	395	5.4	482	35.1	569	3.3	656	22.2	742	27.1
309	40.3	396	2.1	483	35.2	570	6.6	657	23.3	743	27.6
310	38.5	397	0.0	484	35.5	571	9.9	658	24.5	744	27.9
311	37.0	398	0.0	485	35.2	572	13.0	659	25.3	745	28.3
312	35.2	399	0.0	486	35.0	573	14.6	660	25.6	746	28.6
313	33.8	400	0.0	487	35.0	574	16.0	661	26.0	747	28.6
314	32.5	401	0.0	488	35.0	575	17.0	662	26.1	748	28.3
315	31.5	402	0.0	489	34.8	576	17.0	663	26.2	749	28.2
316	30.6	403	2.6	490	34.6	577	17.0	664	26.2	750	28.0
317	30.5	404	5.9	491	34.5	578	17.5	665	26.4	751	27.5
318	30.0	405	9.2	492	33.5	579	17.7	666	26.5	752	26.8
319	29.0	406	12.5	493	32.0	580	17.7	667	26.5	753	25.5
320	27.5	407	15.8	494	30.1	581	17.5	668	26.0	754	23.5
321	24.8	408	19.1	495	28.0	582	17.0	669	25.5	755	21.5
322	21.5	409	22.4	496	25.5	583	16.9	670	23.6	756	19.0
323	20.1	410	25.0	497	22.5	584	16.6	671	21.4	757	16.5
324	19.1	411	25.6	498	19.8	585	17.0	672	18.5	758	14.9
325	18.5	412	27.5	499	16.5	586	17.1	673	16.4	759	12.5
326	17.0	413	29.0	500	13.2	587	17.0	674	14.5	760	9.4
327	15.5	414	30.0	501	10.3	588	16.6	675	11.6	761	6.2
328	12.5	415	30.1	502	7.2	589	16.5	676	8.7	762	3.0
329	10.8	416	30.0	503	4.0	590	16.5	677	5.8	763	1.5
330	8.0	417	29.7	504	1.0	591	16.6	678	3.5	764	1.5
331	4.7	418	29.3	505	0.0	592	17.0	679	2.0	765	0.5
332	1.4	419	28.8	506	0.0	593	17.6	680	0.0	766	0.0
333	0.0	420	28.0	507	0.0	594	18.5	681	0.0	767	3.0
334	0.0	421	25.0	508	0.0	595	19.2	682	0.0	768	6.3
335	0.0	422	21.7	509	0.0	596	20.2	683	0.0	769	9.6
336	0.0	423	18.4	510	0.0	597	21.0	684	0.0	770	12.9
337	0.0	424	15.1	511	1.2	598	21.1			771	15.8
338	0.0	425	11.8	512	3.5	599	21.2	685	0.0	772	17.5

FEDERAL DHEW DRIVING CYCLE^6 (cont.)

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
773	18.4	861	29.1	948	24.0	1,035	0.0	1,122	25.0	1,209	14.0	1,296	26.0	1,322	0.0	1,347	20.3
774	19.5	862	29.0	949	22.0	1,036	0.0	1,123	24.9	1,210	15.5	1,297	26.2	1,323	0.0	1,348	21.3
775	20.7	863	28.1	950	20.1	1,037	0.0	1,124	24.8	1,211	17.0	1,298	27.0	1,324	0.0	1,349	21.9
776	22.0	864	27.5	951	16.9	1,038	0.0	1,125	25.0	1,212	18.6	1,299	27.8	1,325	0.0	1,350	22.1
777	23.2	865	27.0	952	13.6	1,039	0.0	1,126	25.4	1,213	19.7	1,300	28.3	1,326	0.0	1,351	22.4
778	25.0	866	25.8	953	10.3	1,040	0.0	1,127	25.8	1,214	21.0	1,301	29.0	1,327	0.0	1,352	22.0
779	26.5	867	25.0	954	7.0	1,041	0.0	1,128	26.0	1,215	21.5	1,302	29.1	1,328	0.0	1,353	21.6
780	27.5	868	24.5	955	3.7	1,042	0.0	1,129	26.4	1,216	21.3	1,303	29.0	1,329	0.0	1,354	21.1
781	28.0	869	24.8	956	0.4	1,043	0.0	1,130	26.6	1,217	21.8	1,304	28.0	1,330	0.0	1,355	20.5
782	28.3	870	25.1	957	0.0	1,044	0.0	1,131	26.9	1,218	21.5	1,305	24.7	1,331	0.0	1,356	20.0
783	28.9	871	25.5	958	0.0	1,045	0.0	1,132	27.0	1,219	21.2	1,306	21.4	1,332	0.0	1,357	19.6
784	28.9	872	25.7	959	0.0	1,046	0.0	1,133	27.0	1,220	21.5	1,307	18.1	1,333	0.0	1,358	18.5
785	28.9	873	26.2	960	2.0	1,047	0.0	1,134	27.0	1,221	21.8	1,308	14.8	1,334	0.0	1,359	17.5
786	28.8	874	26.9	961	5.3	1,048	0.0	1,135	26.9	1,222	22.0	1,309	11.5	1,335	0.0	1,360	16.5
787	28.5	875	27.5	962	8.6	1,049	0.0	1,136	26.8	1,223	21.9	1,310	8.2	1,336	0.0	1,361	15.5
788	28.3	876	27.3	963	11.9	1,050	0.0	1,137	26.8	1,224	21.7	1,311	4.9	1,337	0.0	1,362	14.0
789	28.3	877	28.4	964	15.3	1,051	0.0	1,138	26.5	1,225	21.5	1,312	1.6	1,338	1.5	1,363	11.0
790	28.3	878	29.0	965	17.5	1,052	0.0	1,139	26.4	1,226	21.5	1,313	0.0	1,339	4.8	1,364	8.0
791	28.2	879	29.2	966	18.6	1,053	1.2	1,140	26.0	1,227	21.4	1,314	0.0	1,340	8.1	1,365	5.2
792	27.6	880	29.1	967	20.0	1,054	4.0	1,141	25.5	1,228	20.1	1,315	0.0	1,341	11.4	1,366	2.5
793	27.5	881	29.0	968	21.1	1,055	7.3	1,142	24.6	1,229	19.5	1,316	0.0	1,342	13.2	1,367	0.0
794	27.5	882	28.9	969	22.0	1,056	10.6	1,143	23.5	1,230	19.2	1,317	0.0	1,343	15.1	1,368	0.0
795	27.5	883	28.5	970	23.0	1,057	13.9	1,144	21.5	1,231	19.6	1,318	0.0	1,344	16.8	1,369	0.0
796	27.5	884	28.1	971	24.5	1,058	17.0	1,145	20.0	1,232	19.8	1,319	0.0	1,345	18.3	1,370	0.0
797	27.5	885	28.0	972	26.3	1,059	18.5	1,146	17.5	1,233	20.0	1,320	0.0	1,346	19.5	1,371	0.0
798	27.5	886	28.0	973	27.5	1,060	20.0	1,147	16.0	1,234	19.5	1,321	0.0				
799	27.6	887	27.6	974	28.1	1,061	21.8	1,148	14.0	1,235	17.5						
800	28.0	888	27.2	975	28.4	1,062	23.0	1,149	10.7	1,236	15.5						
801	28.5	889	26.6	976	28.5	1,063	24.0	1,150	7.4	1,237	13.0						
802	30.0	890	27.0	977	28.5	1,064	24.8	1,151	4.1	1,238	10.0						
803	31.0	891	27.5	978	28.5	1,065	25.6	1,152	0.8	1,239	8.0						
804	32.0	892	27.8	979	27.7	1,066	26.5	1,153	0.0	1,240	6.0						
805	33.0	893	28.0	980	27.5	1,067	26.8	1,154	0.0	1,241	4.0						
806	33.0	894	27.8	981	27.2	1,068	27.4	1,155	0.0	1,242	2.5						
807	33.6	895	28.0	982	26.8	1,069	27.9	1,156	0.0	1,243	0.7						
808	34.0	896	28.0	983	26.5	1,070	28.3	1,157	0.0	1,244	0.0						
809	34.3	897	28.0	984	26.0	1,071	28.0	1,158	0.0	1,245	0.0						
810	34.2	898	27.7	985	25.7	1,072	27.5	1,159	0.0	1,246	0.0						
811	34.0	899	27.4	986	25.2	1,073	27.0	1,160	0.0	1,247	0.0						
812	34.0	900	26.9	987	24.0	1,074	27.0	1,161	0.0	1,248	0.0						
813	33.9	901	26.6	988	22.0	1,075	26.3	1,162	0.0	1,249	0.0						
814	33.6	902	26.5	989	21.5	1,076	24.5	1,163	0.0	1,250	0.0						
815	33.1	903	26.5	990	21.5	1,077	22.5	1,164	0.0	1,251	0.0						
816	33.0	904	26.5	991	21.8	1,078	21.5	1,165	0.0	1,252	1.0						
817	32.5	905	26.3	992	22.5	1,079	20.6	1,166	0.0	1,253	1.0						
818	32.0	906	26.2	993	23.0	1,080	18.0	1,167	0.0	1,254	1.0						
819	31.9	907	26.2	994	22.8	1,081	15.0	1,168	0.0	1,255	1.0						
820	31.6	908	25.9	995	22.8	1,082	12.3	1,169	2.1	1,256	1.0						
821	31.5	909	25.6	996	23.0	1,083	11.1	1,170	5.4	1,257	1.6						
822	30.6	910	25.6	997	22.7	1,084	10.6	1,171	8.7	1,258	3.0						
823	30.0	911	25.9	998	22.7	1,085	10.0	1,172	12.0	1,259	4.0						
824	29.9	912	25.8	999	22.7	1,086	9.5	1,173	15.3	1,260	5.0						
825	29.9	913	25.5	1,000	23.5	1,087	9.1	1,174	18.6	1,261	6.3						
826	29.9	914	24.6	1,001	24.0	1,088	8.7	1,175	21.1	1,262	8.0						
827	29.9	915	23.5	1,002	24.6	1,089	8.6	1,176	23.0	1,263	10.0						
828	29.6	916	22.2	1,003	24.8	1,090	8.8	1,177	23.5	1,264	10.5						
829	29.5	917	21.6	1,004	25.1	1,091	9.0	1,178	23.0	1,265	9.5						
830	29.5	918	21.6	1,005	25.5	1,092	8.7	1,179	22.5	1,266	8.5						
831	29.3	919	21.7	1,006	25.6	1,093	8.6	1,180	20.0	1,267	7.6						
832	28.9	920	22.6	1,007	25.5	1,094	8.0	1,181	16.7	1,268	8.8						
833	28.2	921	23.4	1,008	25.0	1,095	7.0	1,182	13.4	1,269	11.0						
834	27.7	922	24.0	1,009	24.1	1,096	5.0	1,183	10.1	1,270	14.0						
835	27.0	923	24.2	1,010	23.7	1,097	4.2	1,184	6.8	1,271	17.0						
836	25.5	924	24.4	1,011	23.2	1,098	2.6	1,185	3.5	1,272	19.5						
837	23.7	925	24.9	1,012	22.9	1,099	1.0	1,186	0.2	1,273	21.0						
838	22.0	926	25.1	1,013	22.5	1,100	0.0	1,187	0.0	1,274	21.8						
839	20.5	927	25.2	1,014	22.0	1,101	0.1	1,188	0.0	1,275	22.2						
840	19.2	928	25.3	1,015	21.6	1,102	0.6	1,189	0.0	1,276	23.0						
841	19.2	929	25.5	1,016	20.5	1,103	1.6	1,190	0.0	1,277	23.6						
843	20.9	930	25.2	1,017	17.5	1,104	3.6	1,191	0.0	1,278	24.1						
844	21.4	931	25.0	1,018	14.2	1,105	6.9	1,192	0.0	1,279	24.5						
845	22.0	932	25.0	1,019	10.9	1,106	10.0	1,193	0.0	1,280	24.5						
846	22.6	933	25.0	1,020	7.6	1,107	12.8	1,194	0.0	1,281	24.0						
847	23.2	934	24.7	1,021	4.3	1,108	14.0	1,195	0.0	1,282	23.5						
848	24.0	935	24.5	1,022	1.0	1,109	14.5	1,196	0.0	1,283	23.5						
849	25.0	936	24.3	1,023	0.0	1,110	16.0	1,197	0.2	1,284	23.5						
850	26.0	937	24.3	1,024	0.0	1,111	18.1	1,198	1.5	1,285	23.5						
851	26.6	938	24.5	1,025	0.0	1,112	20.0	1,199	3.8	1,286	23.5						
852	26.6	939	25.0	1,026	0.0	1,113	21.0	1,200	6.5	1,287	23.5						
853	26.8	940	25.0	1,027	0.0	1,114	21.2	1,201	9.8	1,288	24.0						
854	27.0	941	24.6	1,028	0.0	1,115	21.3	1,202	12.0	1,289	24.1						
855	27.2	942	24.6	1,029	0.0	1,116	21.4	1,203	12.9	1,290	24.5						
856	27.8	943	24.1	1,030	0.0	1,117	21.7	1,204	13.0	1,291	24.7						
857	28.1	944	24.5	1,031	0.0	1,118	22.5	1,205	12.6	1,292	25.0						
858	28.8	945	25.1	1,032	0.0	1,119	23.0	1,206	12.8	1,293	25.4						
859	28.9	946	25.6	1,033	0.0	1,120	23.8	1,207	13.1	1,294	25.6						
860	29.0	947	25.1	1,034	0.0	1,121	24.5	1,208	13.1	1,295	25.7						

APPENDIX E

Emission Test Log

PHASE I TESTS

TEST	1970 DATE	VEHICLE	TESTS
I-1	7/27	Hybrid B and ICE only	Preliminary set-up tests
I-2	7/28	Hybrid B and ICE only	Preliminary set-up tests
I-3	8/10	Hybrid B and ICE only	Hot 7-mode cycles conc. meas.*

ICE ONLY

HC	CO	CO2	FACTOR	WHC	WCO
483.1	.18	11.24	1.22	24.8	.01
350.7	4.79	10.64	1.08	92.3	1.26
364.8	.87	13.44	1.01	43.7	.10
490.4	5.47	10.96	1.02	30.1	.35
177.5	.85	13.09	1.06	9.4	.04
173.8	1.34	13.68	.91	78.8	.61
1965.2	5.38	10.19	.97	55.0	.15

TOTAL FOR CYCLE 334.1 ppm HC 2.52 CO

HYBRID B
With Carburetor Accelerator Pump

HC	CO	CO2	FACTOR	WHC	WCO
337.0	2.71	12.41	1.03	14.5	.12
156.7	1.34	13.29	1.03	39.2	.33
205.7	2.90	12.55	1.02	24.7	.35
295.2	5.11	11.29	1.02	18.7	.32
158.4	.88	13.21	1.05	8.3	.05
186.1	1.64	13.43	1.00	84.8	.75
798.2	5.22	10.94	1.01	23.3	.15

TOTAL FOR CYCLE 213.4 ppm HC 2.07 CO

HYBRID B
Without Carburetor Accelerator Pump

HC	CO	CO2	FACTOR	WHC	WCO
254.4	1.98	12.63	1.04	11.1	.09
153.2	.64	13.34	1.05	39.2	.16
198.3	2.31	12.61	1.04	24.3	.28
279.9	4.08	11.77	1.03	17.8	.26
119.4	.11	12.92	1.10	6.6	.01
187.0	1.42	13.47	1.01	85.7	.65
740.6	4.74	11.08	1.02	21.8	.14

TOTAL FOR CYCLE 206.3 ppm HC 1.51 CO

I-4	8/11	ICE Only	Nine 7-mode cycles, cold start, CVS meas.**

EMISSIONS - gm/mi

	BAG 1 Cold	BAG 2 Hot	COMPOSITE
HC	15.12	9.78	12.15
CO	148.8	111.5	128.1
CO^2	614.3	465.6	531.7
NO	2.56	1.82	2.15

I-5	8/11	Hybrid B and ICE only	Cruises 15,30, 50 mph conc. meas.

DATA IS PRESENTED IN TABLE II

I-6	8/11	Hybrid B and ICE only	Accelerations 0-50 mph

ICE ONLY

Velocity mph	Time sec
0	0
10	2.7
20	5.5
30	8.5
40	18.5
50	28.5

HYBRID B

Velocity mph	Time sec
0	0
10	.7
20	3.0
30	5.2
40	11.2
50	18.5

I-7	8/12	Hybrid B	Nine 7-mode cycles Cold start, CVS meas.

TEST ABORT -- **HUMAN ERROR**

I-8	8/12	Hybrid B and ICE only	Hot 7-mode cycles Vehicle weight variations conc. meas.

HYBRID B
3,000 lb.

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
326.1	2.43	12.48	107.1	1.03	14.2	.11	4.6
172.2	.77	13.19	1037.1	1.05	44.2	.11	266.4
165.4	2.47	13.05	777.3	1.00	19.6	.29	91.3
329.3	6.09	10.87	65.5	1.01	20.7	.38	4.1
134.6	.83	13.02	309.3	1.07	7.2	.04	16.5
166.5	.78	13.58	1901.2	1.02	77.5	.36	885.2
1469.1	5.14	10.51	77.8	.98	41.9	.15	2.2

TOTAL FOR CYCLE 225.2 ppm HC 1.53 CO 1270.9 ppm NO
152.5 gm/cycle fuel consumption

2,000 lb

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
310.5	2.35	12.61	109.1	1.03	13.4	.10	4.7
196.4	.91	13.16	1088.3	1.04	50.0	.25	277.1
143.7	1.36	13.16	668.2	1.03	17.5	.17	81.6
265.2	4.15	11.88	112.0	1.02	16.7	.26	7.1
123.2	.20	12.90	356.7	1.10	6.8	.01	19.7
146.3	.49	13.79	2285.2	1.02	67.9	.23	1060.5
760.9	4.31	11.42	157.5	1.01	22.2	.13	4.6

TOTAL FOR CYCLE 194.6 ppm HC 1.14 CO 1455.1 ppm NO
139.5 gm/cycle fuel consumption

I-8 (continued)

4,000 lb.

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
263.1	2.53	12.61	148.7	1.02	11.3	.11	6.4
223.6	1.74	12.90	867.6	1.03	56.4	.44	218.8
161.8	2.75	12.85	727.5	1.01	19.2	.33	86.4
275.9	5.51	11.23	114.2	1.01	17.3	.35	7.2
123.6	.30	13.25	475.1	1.07	6.6	.02	25.5
135.5	.65	13.73	2212.9	1.02	62.8	.30	1026.4
2082.0	5.72	9.91	104.4	.96	57.9	.16	2.9

TOTAL FOR CYCLE 231.5 ppm HC 1.70 CO 1372.5 ppm NO
163.0 gm/cycle fuel consumption

3,000 LB
ICE ONLY

285.4	2.35	12.29	101.1	1.05	12.6	.10	4.5
312.5	4.43	11.14	495.3	1.06	80.6	1.14	127.9
148.4	2.45	13.05	767.8	1.00	17.6	.29	90.8
914.5	8.73	8.81	109.9	1.02	57.1	.55	6.1
165.9	.21	12.85	446.3	1.10	9.2	.01	24.6
173.2	1.33	13.66	2061.5	.91	78.7	.60	936.7
2438.5	6.17	9.39	102.3	.96	67.8	.17	2.8

TOTAL FOR CYCLE 324.3 ppm HC 2.88 CO 1193.8 ppm NO
178.5 gm/cycle fuel consumption

2,000 lb.

451.8	2.33	12.37	114.1	1.03	19.6	.10	4.1
326.1	3.37	11.29	396.3	1.09	86.8	.89	105.1
150.9	1.89	13.41	935.9	.91	17.7	.22	110.2
725.8	7.75	9.34	156.4	1.03	46.6	.41	10.0
173.1	.54	13.13	516.1	1.06	9.2	.03	27.4
178.7	1.20	13.75	2372.1	.91	80.9	.54	1074.6
2070.3	5.26	10.10	120.7	.97	58.1	.15	3.4

TOTAL FOR CYCLE 318.9 ppm HC 2.43 CO 1335.4 ppm NO
162.5 gm/cycle fuel consumption

4,000 lb.

259.3	.18	11.71	182.4	1.11	13.1	.01	9.2
312.5	3.94	11.06	339.6	1.08	82.5	1.04	89.7
293.4	6.81	10.56	279.4	1.01	35.1	.81	33.4
1247.1	8.75	8.34	80.2	1.03	79.6	.56	5.1

I-8 4,000 lb. (continued)

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
317.2	2.26	12.88	424.2	1.01	15.1	.11	21.4
151.7	1.78	13.28	1779.7	1.01	69.7	.82	818.4
2625.1	6.54	9.18	114.6	.95	72.2	.18	3.2

TOTAL FOR CYCLE 368.9 ppm HC 3.54 CO 979.7 ppm NO
185.0 gm/cycle fuel consumption

I-9 8/13 Hybrid B Nine 7-mode cycles
Cold Start, CVS meas.

EMISSIONS - gm/mi

	BAG 1 Cold	BAG 2 Hot	COMPOSITE
HC	12.00	5.01	6.78
CO	84.2	50.1	65.3
CO^2	506.9	462.3	482.1
NO	1.75	2.35	2.08

PHASE II TESTS

TEST	DATE	VEHICLE	TESTS
II-1	10/8	Hybrid C	Nine 7-mode cycles Cold Start, CVS meas.

TEST ABORT -- ONE CYLINDER MISFIRING

II-2	10/8	Hybrid C	Hot 7-mode cycles Vehicle weight variations, conc. meas.

2,000 lb.
One Cylinder Misfiring

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
2559.6	.43	8.97	118.1	1.21	130.4	.02	6.1
2982.4	3.14	7.78	479.3	1.15	838.7	.88	134.8
2869.9	4.57	7.07	297.5	1.16	393.6	.63	40.8
2847.7	5.75	6.20	86.6	1.19	210.4	.43	6.4
2530.3	1.29	9.21	368.8	1.15	145.5	.07	21.2
2719.7	1.25	9.21	1649.4	1.13	1403.3	.64	850.8
2667.1	2.05	8.48	227.1	1.17	90.5	.07	7.7

TOTAL FOR CYCLE 3210.9 ppm HC 2.74 CO 1066.8 ppm NO

2,000 lb.
14.5/1 AF

172.2	.53	13.93	138.8	1.01	7.3	.02	5.9
133.4	1.03	13.71	630.5	1.00	32.6	.25	154.1
140.4	3.99	12.26	430.3	1.01	16.7	.47	51.0
156.6	4.53	11.98	141.6	1.00	9.8	.28	8.8
123.2	.98	14.06	651.1	.99	6.1	.05	32.2
156.3	2.28	13.30	1284.2	.99	70.4	1.03	579.3
135.5	2.73	13.05	482.8	.99	3.9	.08	13.9

TOTAL FOR CYCLE 146.6 ppm HC 2.19 CO 844.9 ppm NO

169.9 gm/cycle fuel consumption

II-2 (continued)

3,000 lb.
13.5/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
79.9	.25	13.54	261.5	1.05	3.5	.01	11.6
106.3	1.46	13.48	671.1	1.01	26.2	.36	165.6
177.1	5.78	11.05	354.8	1.02	21.5	.61	42.9
186.6	8.51	9.58	101.5	1.03	11.9	.54	6.5
98.4	.90	14.06	643.8	.99	4.9	.04	31.9
139.9	2.16	13.43	1605.9	.99	62.9	.97	721.9
190.0	4.90	11.67	153.5	1.01	5.6	.14	4.5

TOTAL FOR CYCLE 136.5 ppm HC 2.77 CO 984.8 ppm NO
186.4 gm/cycle fuel consumption

4,000 lb.
15.5/1 AF

153.2	.55	13.98	168.5	1.00	6.5	.02	7.1
146.0	1.11	13.71	871.5	1.00	35.7	.29	212.9
110.9	1.27	13.90	3327.1	.99	12.9	.15	387.9
115.7	1.44	13.79	1583.4	.99	7.1	.09	97.1
92.3	.62	14.04	864.5	1.00	4.6	.03	43.3
130.1	2.14	13.33	1604.5	.91	58.9	.97	726.8
437.1	5.26	11.26	229.3	1.01	12.8	.15	6.7

TOTAL FOR CYCLE 138.4 ppm HC 1.71 CO 1481.4 ppm NO
203.4 gm/cycle fuel consumption

II-3 10/8 Hybrid C and ICE only Cruises 15, 30, 50 mph Conc. meas.

DATA IS PRESENTED IN TABLE II

II-4 10/8 Hybrid C Accelerations 0-50 mph

VELOCITY mph	TIME sec
0	0
10	1.2
20	2.5
30	4.5
40	8.0
50	13.0

II-5 10/9 Hybrid C Seven 7-mode cycles
Cold start, conc. meas.

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
6003.9	.43	4.48	41.6	1.21	326.9	.02	2.3
2897.3	.54	9.54	52.6	1.12	791.2	.15	14.3
618.6	3.77	12.23	462.1	.98	71.5	.44	53.4
511.7	6.51	10.27	76.1	1.03	32.5	.42	4.8
305.2	2.61	12.58	164.6	1.02	15.6	.13	8.4
237.8	.53	13.29	999.2	1.05	113.5	.25	476.8
428.5	2.79	11.77	116.6	1.06	13.2	.09	3.6
TOTAL FOR CYCLE 1			1363.7 ppm HC		1.41 CO	563.5 ppm NO	
844.9	.84	12.31	95.2	1.06	37.7	.04	4.2
377.1	1.44	13.29	493.4	1.00	92.4	.35	120.1
237.5	5.19	11.59	307.3	1.00	28.1	.61	36.3
828.5	8.12	9.22	48.6	1.02	52.5	.51	3.1
274.0	1.58	13.43	146.8	.91	13.7	.08	7.3
186.1	.35	13.55	1438.5	1.04	88.0	.17	680.3
428.5	3.74	11.53	77.8	1.04	12.1	.11	2.4
TOTAL FOR CYCLE 2			325.0 ppm HC		1.88 CO	854.7 ppm NO	
489.1	.49	12.77	103.1	1.07	21.1	.02	4.6
291.5	2.56	12.49	353.6	1.03	73.1	.64	88.7
217.9	5.54	11.31	249.9	1.01	25.1	.66	29.8
591.4	7.94	9.46	50.7	1.03	37.8	.51	3.2
224.6	1.95	13.24	154.6	1.00	11.3	.01	7.7
184.2	.46	13.73	1269.9	1.02	85.7	.21	590.8
205.8	2.52	12.71	278.3	1.02	6.1	.07	8.2
TOTAL FOR CYCLE 3			261.8 ppm HC		2.22 CO	732.8 ppm NO	
392.7	.73	13.07	101.1	1.04	17.2	.03	4.4
235.8	2.35	12.79	372.1	1.02	58.6	.58	92.4
231.9	6.57	10.74	225.9	1.01	27.8	.79	27.1
690.0	8.50	9.11	52.9	1.02	43.7	.54	3.3
279.9	2.53	13.02	150.6	.99	13.9	.13	7.5
256.3	.71	13.66	1608.4	1.01	118.3	.33	741.8
363.9	4.08	11.81	89.1	1.01	10.7	.12	2.6
TOTAL FOR CYCLE 4			289.8 ppm HC		2.51 CO	878.9 ppm NO	

II-5 (continued)

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
253.5	.55	13.19	105.1	1.05	11.2	.02	4.7
184.4	1.03	13.56	612.5	1.01	45.6	.25	151.7
173.6	5.53	11.31	257.5	1.01	20.8	.66	30.8
404.1	8.35	9.39	54.9	1.03	25.9	.54	3.5
199.8	2.99	12.63	150.6	1.01	10.1	.15	7.6
147.3	.98	13.89	1764.6	.91	66.8	.44	799.8
243.7	3.94	12.17	126.8	1.01	7.1	.11	3.7

TOTAL FOR CYCLE 6 187.3 ppm HC 2.18 CO 1000.1 ppm NO

245.6	.43	13.41	109.1	1.04	10.8	.02	4.8
181.4	1.11	13.64	469.1	1.00	44.4	.29	114.8
186.0	4.81	11.84	362.6	1.00	22.0	.57	42.9
514.1	8.62	9.28	61.3	1.02	32.6	.55	3.9
222.7	3.06	12.71	158.6	1.00	11.1	.15	7.9
185.1	1.36	13.70	1478.5	.99	83.6	.61	668.4
235.8	3.74	12.24	163.6	1.01	6.9	.11	4.8

TOTAL FOR CYCLE 7 211.4 ppm HC 2.30 CO 847.3 ppm NO

AV 1-4 559.8 ppm HC 2.02 CO 757.2 ppm NO
AV 6-7 199.5 ppm HC 2.24 CO 924.2 ppm NO

II-6 10/9 Hybrid D Nine 7-mode cycles
Cold start, CVS meas.

EMISSIONS gm/mi

	BAG 1 Cold	BAG 2 Hot	COMPOSITE
HC	12.0	4.1	7.6
CO	83.1	64.6	72.8
NO	1.23	2.92	2.17

PHASE III TESTS

TEST	DATE	VEHICLE	TESTS
III-1	11/12	ICE Only	Nine 7-mode cycles Cold start, conc. meas.

TEST ABORT - DRIVER AID MALFUNCTIONED

TEST	DATE	VEHICLE	TESTS
III-2	11/12	ICE Only	Hot 7-mode cycles conc. meas.

12/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
816.4	5.88	10.08	81.1	1.04	35.7	.26	3.5
325.9	8.96	9.27	121.7	1.03	81.6	2.24	30.5
471.9	9.79	8.81	139.6	1.01	56.3	1.17	16.7
2316.4	9.23	5.91	60.8	1.11	159.7	.64	4.1
264.9	3.45	12.38	225.3	1.01	13.3	.17	11.[illegible]
275.0	7.55	10.05	274.2	1.03	128.3	3.53	127.1
1813.3	7.50	9.09	58.1	.98	51.5	.21	1.6

TOTAL FOR CYCLE 525.1 ppm HC 8.21 CO 195.8 ppm NO

TEST	DATE	VEHICLE	TESTS
III-3	11/12	Hybrid C-1	Hot 7-mode cycles Conc. meas.

14.5/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
354.0	5.36	10.86	78.8	1.04	15.5	.23	3.4
317.2	6.23	10.32	362.6	1.05	81.4	1.51	93.0
198.3	3.67	12.48	650.8	.91	23.3	.43	76.6
1064.5	9.77	8.03	170.4	1.03	67.9	.62	10.9
277.8	3.34	12.68	319.8	.99	13.7	.16	15.8
218.1	3.14	12.53	990.2	1.01	100.2	1.44	455.1
1535.5	7.68	8.58	95.3	1.03	45.8	.23	2.5

TOTAL FOR CYCLE 347.8 ppm HC 4.72 CO 657.6 ppm NO

III-4 11/12 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

18/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
149.4	.27	13.11	204.9	1.08	6.8	.01	9.3
419.9	.27	11.09	275.5	1.24	126.1	.08	83.4
101.8	.24	11.21	225.3	1.27	15.2	.04	33.7
254.1	4.92	11.44	172.9	1.02	16.2	.31	10.1
118.5	.23	12.00	412.1	1.18	7.0	.01	24.4
643.8	.31	10.52	936.7	1.27	371.7	.23	540.4
359.1	1.39	13.09	766.8	1.02	10.7	.04	22.7

TOTAL FOR CYCLE 554.1 ppm HC .72 CO 724.6 ppm NO

III-5 11/12 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

16.5/1 AF

142.7	1.22	13.63	182.4	1.01	6.0	.05	7.7
127.5	.53	12.11	461.5	1.15	35.8	.15	129.4
65.7	.23	12.06	905.5	1.18	9.2	.03	126.4
211.0	5.11	11.41	276.2	1.02	13.3	.33	17.4
97.1	.26	12.28	752.1	1.16	5.6	.01	43.5
94.3	1.28	12.05	1083.4	1.13	48.6	.66	557.8
107.0	.73	13.43	1162.5	1.04	3.2	.02	35.1

TOTAL FOR CYCLE 121.6 ppm HC 1.25 CO 917.2 ppm NO

III-6 11/13 Hybrid C-1 Nine 7-mode cycles
Cold start, CVS meas.

TEST ABORT - TRANSMISSION DOES NOT FUNCTION PROPERLY

III-7 11/19 Hybrid C-1 and Cruises 15,30,50 mph
ICE only Conc. meas.

DATA IS PRESENTED IN TABLE II

III-8 11/20 ICE Only Nine 7-mode cycles
Cold Start, CVS meas.

TEST ABORT - ICE SET UP TOO RICH

III-9 11/20 ICE Only Hot 7-mode cycles
Vehicle weight variation
Conc. meas.

3,000 lb.
14/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
613.4	5.74	10.55	85.5	1.02	28.1	.25	3.7
348.7	8.07	10.36	156.3	.98	83.4	1.98	37.4
267.5	5.76	11.69	344.7	.98	30.8	.66	39.7
996.5	8.95	8.97	105.7	.91	61.6	.55	6.5
380.7	10.65	9.07	146.6	.98	18.6	.52	7.2
301.9	5.89	11.75	574.2	.96	132.5	2.59	251.1
2941.4	6.33	9.05	130.2	.94	30.2	.17	3.6

TOTAL FOR CYCLE 436.1 ppm HC 6.68 CO 349.1 ppm NO

2,000 lb.

787.7	6.81	10.22	69.8	1.01	33.6	.27	8.1
413.1	9.79	9.41	89.5	.98	98.9	2.84	21.4
274.5	5.51	11.78	326.5	.97	31.5	.64	37.5
908.6	8.74	9.11	55.2	1.00	56.4	.54	3.4
319.1	4.32	12.47	182.4	.97	15.4	.21	8.8
296.5	5.85	11.66	462.8	.97	130.1	2.58	204.4
6589.6	6.91	9.16	58.1	.73	140.2	.15	1.2

TOTAL FOR CYCLE 507.8 ppm HC 6.74 CO 279.4 ppm NO

4,000 lb

625.0	6.01	10.47	67.5	1.02	26.9	.26	2.9
341.1	8.89	9.90	140.1	.98	82.1	2.13	33.6
243.8	5.13	12.00	396.1	.97	28.0	.59	45.6
1041.0	9.24	8.65	79.2	1.01	64.1	.58	4.9
304.0	2.38	12.71	328.8	.95	14.5	.11	15.6
289.9	5.02	12.13	574.2	.97	124.8	2.21	252.2
2741.2	6.78	8.70	66.1	.94	76.5	.19	1.5

TOTAL FOR CYCLE 417.2 ppm HC 6.06 CO 356.6 ppm NO

III-10 11/23 Hybrid C-1 Nine 7-mode cycles
Cold Start, CVS meas.

EMISSIONS gm/mi

	BAG 1 Cold	BAG 2 Hot	COMPOSITE
HC	7.92	3.14	5.26
CO	23.0	31.8	27.9
NO	1.60	1.58	1.59

III-11 11/23 ICE Only Nine 7-mode cycles
Cold Start, CVS meas.

EMISSIONS gm/mi

	BAG 1 Cold	BAG 2 Hot	COMPOSITE
HC	13.04	9.00	10.80
CO	162.1	167.4	165.0
NO	.36	.74	.58

III-12 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. meas.

15.5/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
189.9	2.06	13.11	67.5	1.01	8.1	.09	2.9
205.7	.36	12.77	528.3	1.01	55.1	.01	141.6
83.7	.11	13.64	869.5	1.05	10.3	.02	107.5
982.4	8.45	8.64	122.5	1.04	63.3	.54	7.9
265.9	.72	11.55	168.9	1.19	15.8	.04	10.0
169.5	.21	12.39	555.7	1.14	87.7	.16	287.7
181.2	2.04	13.30	283.7	.91	5.2	.06	8.2

TOTAL FOR CYCLE 245.4 ppm HC 1.01 CO 565.4 ppm NO

III-13 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. meas.

17/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
2583.1	.21	7.37	15.8	1.41	152.5	.02	.9
2179.7	.27	8.07	68.9	1.37	729.7	.09	23.0
432.0	.19	11.87	574.6	1.17	59.4	.03	79.0
2083.1	.52	7.03	84.0	1.52	196.1	.05	7.9
5261.7	.11	1.15	.0	2.10	553.1	.01	.0
1931.6	.28	9.47	281.3	1.24	1089.3	.16	158.5
3670.9	.86	4.15	6.1	1.61	180.5	.04	.3

TOTAL FOR CYCLE 2959.8 ppm HC .39 CO 269.6 ppm NO

III-14 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. meas.

15/1 AF -14° SA

818.8	5.38	10.27	51.8	1.05	36.0	.24	2.8
985.5	1.69	10.85	450.2	1.13	272.7	.47	124.6
217.9	2.64	12.99	576.8	.91	25.6	.31	67.8
2066.4	7.46	8.06	91.2	1.03	132.2	.48	5.8
275.0	.29	13.96	515.6	1.01	13.8	.01	25.9
170.9	.33	13.18	466.1	1.07	83.2	.16	227.6
359.1	1.75	12.69	65.1	1.04	10.8	.05	1.1

TOTAL FOR CYCLE 574.2 ppm HC 1.72 CO 455.9 ppm NO

III-15 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

A/F TOO LEAN -- ICE DID NOT FUNCTION

III-16 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

A/F TOO LEAN -- ICE DID NOT FUNCTION

III-17 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

16/1 AF -6° SA

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
412.7	.36	10.08	33.8	1.35	23.4	.02	1.9
559.8	.96	12.00	537.3	1.11	151.3	.26	145.0
111.8	.87	13.51	889.5	1.03	13.6	.11	108.1
252.1	3.07	12.06	139.3	1.04	16.3	.11	9.0
259.3	.19	13.00	461.5	1.08	14.0	.01	24.1
122.3	.39	13.40	704.3	1.05	58.7	.19	338.1
261.2	.98	12.12	99.9	1.12	8.5	.03	3.3

TOTAL FOR CYCLE 285.4 ppm HC .81 CO 630.1 ppm NO

III-18 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

16/1 AF -14° SA

42.3	.21	12.99	360.4	1.10	1.1	.01	16.7
45.1	.38	13.41	921.9	1.06	11.7	.01	238.7
55.7	.44	13.78	1500.0	1.03	6.8	.05	182.3
131.9	2.17	12.48	225.7	1.06	8.6	.14	14.8
491.2	.21	11.77	245.5	1.17	28.7	.01	14.3
175.2	.32	13.68	1205.5	1.03	82.3	.15	566.6
60.4	.32	12.26	471.9	1.16	2.0	.01	15.9

TOTAL FOR CYCLE 141.1 ppm HC .48 CO 1048.8 ppm NO

III-19 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

A/F TOO LEAN - ICE DID NOT FUNCTION

III-22 11/24 Hybrid C-1 Hot 7-mode cycles
Conc. Meas.

4,000 LB 14/1 AF

HC	CO	CO2	NO	FACTOR	WHC	WCO	WNO
582.6	5.91	9.93	72.1	1.07	26.2	.27	3.2
707.2	3.06	10.67	649.8	1.12	192.9	.83	177.1
179.8	4.57	11.86	700.6	1.01	21.4	.54	83.5
495.1	8.85	8.77	105.7	1.05	32.4	.58	6.9
321.1	.21	11.42	132.9	1.22	19.5	.02	8.1
138.1	.62	13.07	1019.9	1.07	67.7	.30	497.3
531.4	4.76	11.18	116.2	1.02	15.8	.14	3.5

TOTAL FOR CYCLE 375.7 ppm HC 2.69 CO 779.3 ppm NO

III-23 11/25 Hybrid C-1 DHEW Cycle
CVS Meas.

EMISSIONS gm/mi

HC	3.15
CO	29.6
NO	1.0

PHASE I NOTES

Hybrid B Power Train included the following:

- ICE with single venturi, 1-9/16" diameter carburetor without accelerating pump or choke.
- Single venturi intake manifold 1-3/4" diameter legs with hot air heating directed to the external carburetor flange.
- 24V electrical system.
- Bang-bang electric control system.

ICE Power Train included the following:

- ICE with single barrel 1-4/16" diameter carburetor with accelerating pump and choke.
- Single barrel intake manifold 1-3/4" diameter legs with hot air heating directed to the external carburetor flange.

PHASE II NOTES

Hybrid C Power Train included the following:

- ICE with single venturi, 1-9/16" diameter carburetor without accelerating pump and choke.
- Single barrel intake manifold 1-3/4" diameter legs with hot air supplied to the intake system just ahead of the carburetor intake.
- 24-48V electrical system.
- Throttle delay mechanism.

PHASE III NOTES

Hybrid C-1 Power Train included the following:

- ICE with single venturi carburetor and manifold one inch diameter legs.
- Hot exhaust gas heating of ICE manifold legs.
- Hot air heating supplied to the intake system just ahead of ICE carburetor intake.
- No carburetor accelerator pump.
- No carburetor choke.
- 24-48V electrical system.
- Throttle delay mechanism.

ICE only Power Train included the following:

- Same ICE features as described above.
- Carburetor acceleration pump.
- Carburetor choke.

GENERAL NOTES

*Conc. Meas. = Concentration measurement

**CVS Meas. = Constant volume sampler measurement

A/F = Air/Fuel ratio

SA = Spark advance

HYBRID C 7-MODE DRIVING CYCLE

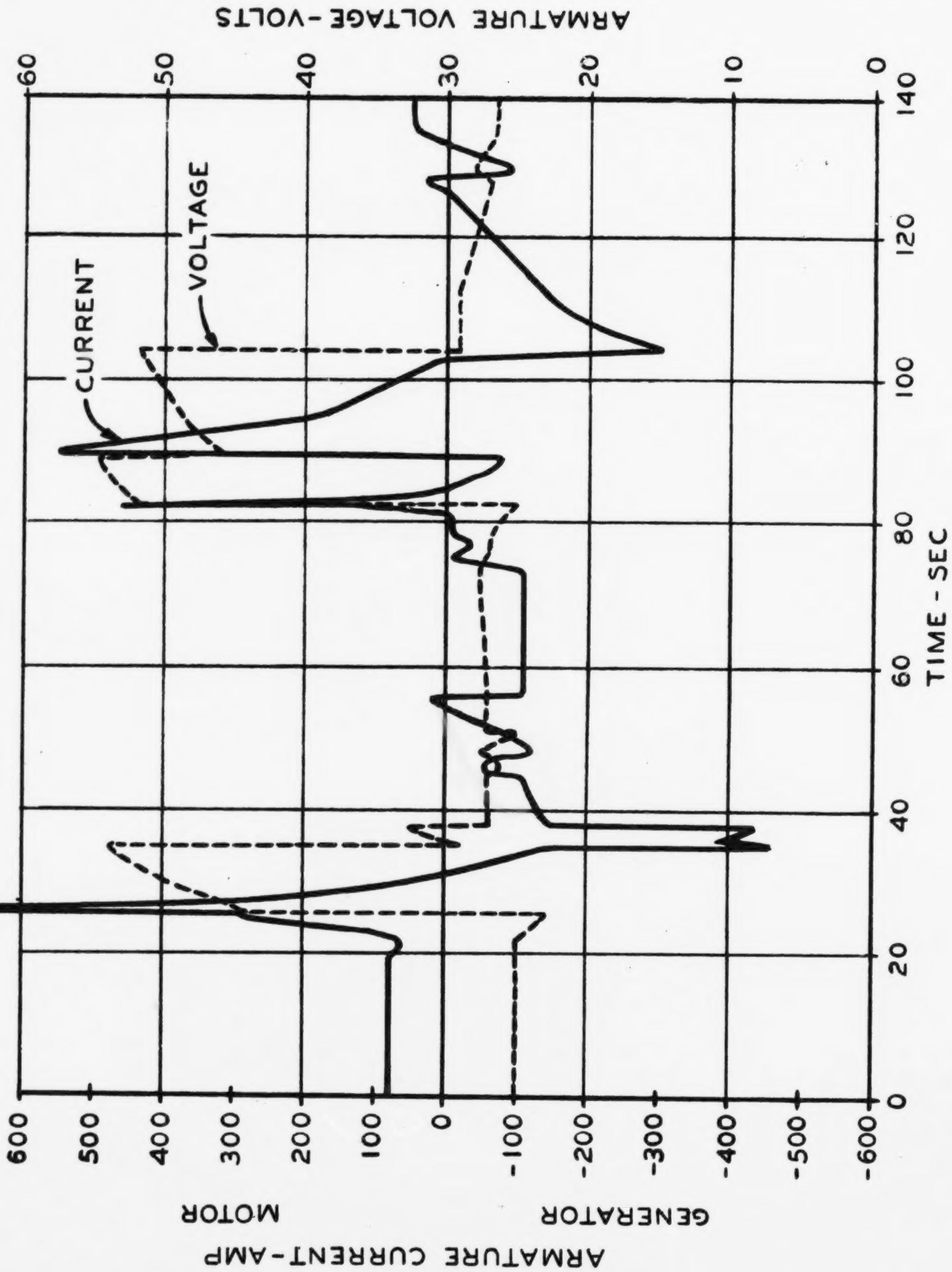


FIGURE F-1

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